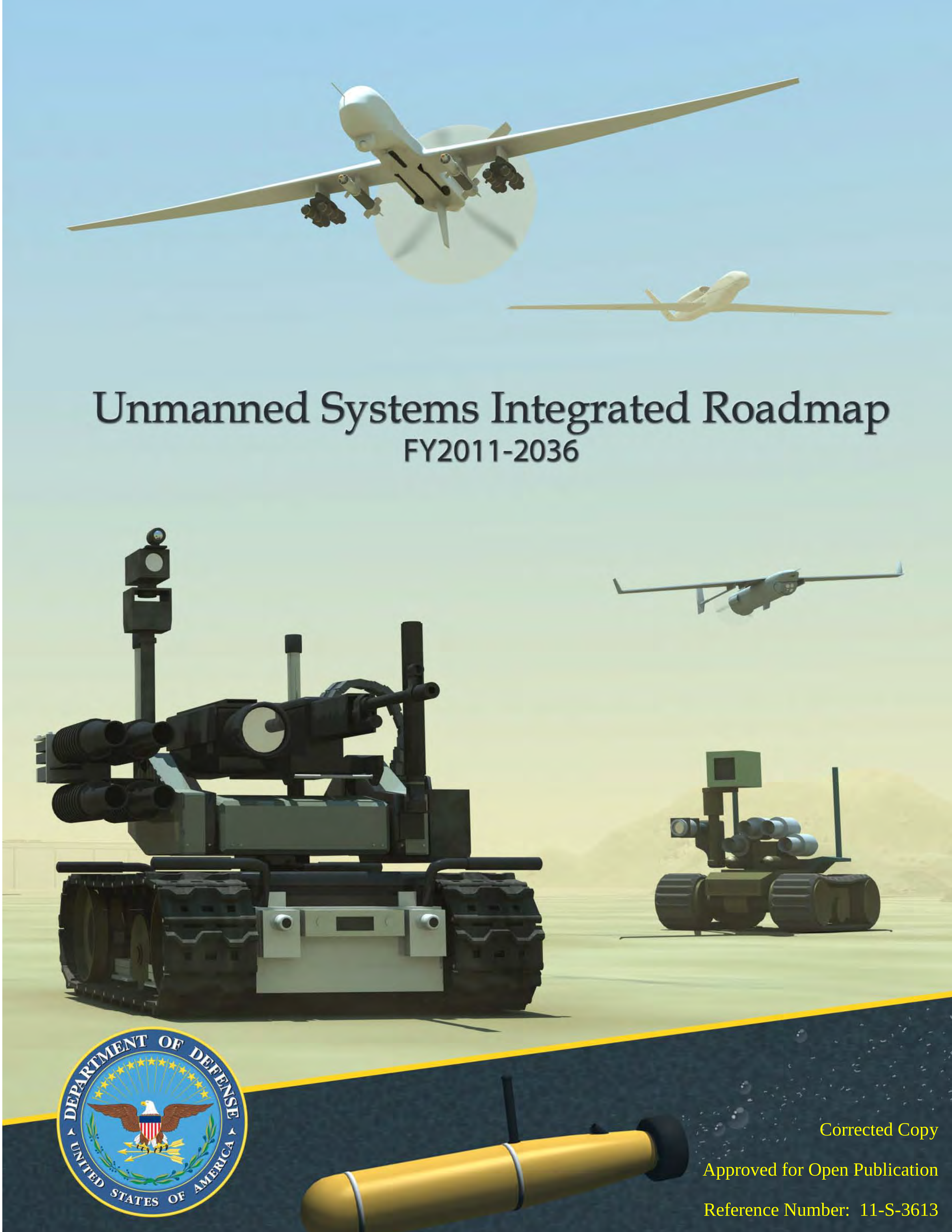
Unmanned Systems Integrated Roadmap

FY2011-2036



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THE UNMANNED SYSTEMS INTEGRATED ROADMAP

FY2011-2036

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EXECUTIVE SUMMARY

U.S. and allied combat operations continue to highlight the value of unmanned systems in the modern combat environment. Combatant Commanders (CCDRs) and warfighters value the inherent features of unmanned systems, especially their persistence, versatility, and reduced risk to human life. The U.S. military Services are fielding these systems in rapidly increasing numbers across all domains: air, ground, and maritime. Unmanned systems provide diverse capabilities to the joint commander to conduct operations across the range of military operations: environmental sensing and battlespace awareness; chemical, biological, radiological, and nuclear (CBRN) detection; counter-improvised explosive device (C-IED) capabilities; port security; precision targeting; and precision strike. Furthermore, the capabilities provided by these unmanned systems continue to expand.

The Department of Defense (DoD) has been successful in rapidly developing and fielding unmanned systems. DoD will continue to focus on responding rapidly to CCDR requirements, while ensuring systems are acquired within the framework of DoD's new wide-ranging Efficiencies Initiatives[1]. In the fiscal environment facing the Nation, DoD, in concert with industry, must pursue investments and business practices that drive down life-cycle costs for unmanned systems. Affordability will be treated as a key performance parameter (KPP) equal to, if not more important than, schedule and technical performance. DoD will partner with industry to continue to invest in unmanned systems technologies while providing incentives for industry to implement cost-saving measures and rewarding industry members that routinely demonstrate exemplary performance.

> My Acquisition Decision Memorandum (ADM) approving formal program commencement of the program will contain an affordability target to be treated by the Program Manager like a Key Performance Parameter (KPP) such as speed, power, or data rate ….
>
> *–Under Secretary of Defense Memorandum for Acquisition Professionals, Better Buying Power, September 2010*[1]

This document provides a DoD vision for the continuing development, fielding, and employment of unmanned systems technologies. Since publication of the last DoD Roadmap in 2009, the military Services have released individual Service roadmaps or related strategy documents. This roadmap defines a common vision, establishes the current state of unmanned systems in today's force, and outlines a strategy for the common challenges that must be addressed to achieve the shared vision.

The challenges facing all military Services in the Department include:

1) Interoperability: To achieve the full potential of unmanned systems, these systems must operate seamlessly across the domains of air, ground, and maritime and also operate

[1] Better Buying Power, Guidance for Obtaining Greater Efficiency and Productivity in Defense Spending, OUSD(AT&L) Memo, Dr. Ashton B. Carter, 14 September 2010.

seamlessly with manned systems. Robust implementation of interoperability tenets will contribute to this goal while also offering the potential for significant life-cycle cost savings.

2) Autonomy: Today's iteration of unmanned systems involves a high degree of human interaction. DoD must continue to pursue technologies and policies that introduce a higher degree of autonomy to reduce the manpower burden and reliance on full-time high-speed communications links while also reducing decision loop cycle time. The introduction of increased unmanned system autonomy must be mindful of affordability, operational utilities, technological developments, policy, public opinion, and their associated constraints.

3) Airspace Integration (AI): DoD must continue to work with the Federal Aviation Administration (FAA) to ensure unmanned aircraft systems (UAS) have routine access to the appropriate airspace needed within the National Airspace System (NAS) to meet training and operations requirements. Similar efforts must be leveraged for usage of international airspace.

4) Communications: Unmanned systems rely on communications for command and control (C2) and dissemination of information. DoD must continue to address frequency and bandwidth availability, link security, link ranges, and network infrastructure to ensure availability for operational/mission support of unmanned systems. Planning and budgeting for UAS Operations must take into account realistic assessments of projected SATCOM bandwidth, and the community must move toward onboard pre-processing to pass only critical information.

5) Training: An overall DoD strategy is needed to ensure continuation and Joint training requirements are in place against which training capabilities can be assessed. Such a strategy will improve basing decisions, training standardization, and has the potential to promote common courses resulting in improved training effectiveness and efficiency.

6) Propulsion and Power: The rapid development and deployment of unmanned systems has resulted in a corresponding increased demand for more efficient and logistically supportable sources for propulsion and power. In addition to improving system effectiveness, these improvements have the potential to significantly reduce life-cycle costs.

7) Manned-Unmanned (MUM) Teaming: Today's force includes a diverse mix of manned and unmanned systems. To achieve the full potential of unmanned systems, DoD must continue to implement technologies and evolve tactics, techniques and procedures (TTP) that improve the teaming of unmanned systems with the manned force.

This Roadmap leverages individual Service roadmaps and visions, and identifies challenges that might stand in the way of maturing those visions to a shared Joint vision. The vignettes provided at the beginning of the Roadmap give the reader a glimpse into potential unmanned systems capabilities. They do not serve as requirements—the individual Services will continue to identify requirements gaps and utilize the Joint Capabilities Integration and Development System (JCIDS) to determine which requirements to fund. The chapters that follow the vignettes identify core areas that are challenges for further growth in unmanned systems and chart out science, technology, and policy paths that will enable unmanned systems to fulfill an expanding role in

supporting the warfighter. Success in each of these areas is critical to achieve DoD's shared vision and realize the full potential of unmanned systems at an affordable cost.

> … the ability to understand and control future costs from a program's inception is critical to achieving affordability requirements.
>
> *–Under Secretary of Defense Memorandum for Acquisition Professionals, Better Buying Power, September 2010*[1]

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1 INTRODUCTION/SCOPE

1.1 Purpose

The purpose of this document is to describe a vision for the continued integration of unmanned systems into the Department of Defense (DoD) Joint force structure and to identify steps that need to be taken to affordably execute this integration. DoD has seen rapid growth, sparked in large part by the demands of the current combat environment, in the development, procurement, and employment of unmanned systems. Today's deployed forces have seen how effective unmanned systems can be in combat operations. This experience has created expectations for expanding the roles for unmanned systems in future combat scenarios. This Roadmap establishes a vision for the next 25 years and outlines major areas where DoD and industry should focus to ensure the timely and successful adoption of unmanned systems.

1.2 Scope

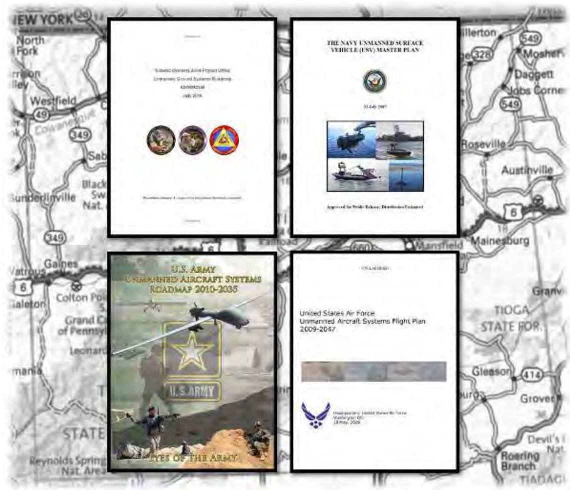
This Roadmap follows the path originally laid out in the 2007 and 2009 Roadmaps in addressing all three unmanned domains: air, ground, and maritime. However, this document deviates from the earlier editions, primarily as a result of the following:

- An Unmanned Systems Roadmap survey conducted by the Office of the Under Secretary of Defense (Acquisition, Technology, and Logistics) (OUSD(AT&L))
- Publication of service-specific roadmaps for unmanned systems

Shortly after the publication of the 2009 Roadmap, OUSD(AT&L) conducted a survey of key stakeholders and users of the Roadmap. The survey sampled a wide audience, including: Office of the Secretary of Defense (OSD), Service headquarters, warfighting commands, Service acquisition organizations, Service laboratories, multiple Joint organizations, other government agencies, industry (both large and small businesses), and academia. One of the major outcomes of this survey was a decision to capture the catalog function of the Roadmap in a separate, online tool. The reason for this decision is that the online tool provides greater functionality than that of the two-dimensional, hard-copy catalog, including the capability for more frequent updates than the biennial printed Roadmap. The catalog can be found on the Unmanned Warfare Information Repository site at: **https://extranet.acq.osd.mil/uwir/**.

The survey also helped define the audience for the 2011 edition. This Roadmap provides a common vision and problem set to help shape military Service investments. The document also describes DoD's direction to help industry participants shape their investments, particularly with respect to independent research and development.

Since the publication of the 2009 Roadmap, each military Service has developed its own roadmap or equivalent document (listed in Appendix A). The U.S. Air Force (USAF) released its "Unmanned Aircraft Systems Flight Plan" in 2009 outlining an actionable plan across the diverse spectrum of doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy (DOTMLPF-P). In 2009, the U.S. Army published the "Unmanned Ground Systems Roadmap," providing a common resource document for Army and U.S. Marine Corps (USMC) stakeholders in unmanned ground vehicles (UGVs). The Army released its unmanned



aircraft systems (UAS) Roadmap in 2010, which established a broad vision for developing, organizing, and employing UAS across the spectrum of Army operations. In November 2009, the USMC published its “Concept of Operations for USMC Unmanned Aircraft Systems Family of Systems (CONOPS for USMC UAS FoS).” Finally, the U.S. Navy published its “Information Dominance Roadmap for Unmanned Systems” in December 2010. In light of these recent publications (see right), this Roadmap was tailored to focus on common issues facing all Services as well as to articulate a vision for achieving these goals in today’s fiscal environment. The goal for this document is to serve as a single, unified source to clearly articulate the DoD common vision for unmanned systems and to identify a common problem set facing DoD in maximizing the military utility offered by these versatile and innovative systems.

2 VISION

The Department of Defense's vision for unmanned systems is the seamless integration of diverse unmanned capabilities that provide flexible options for Joint Warfighters while exploiting the inherent advantages of unmanned technologies, including persistence, size, speed, maneuverability, and reduced risk to human life. DOD envisions unmanned systems seamlessly operating with manned systems while gradually reducing the degree of human control and decision making required for the unmanned portion of the force structure.

… to ensure safe, effective and supportable capabilities are provided while meeting cost, schedule and performance. The parallel vision is to provide continuous improvement of unmanned system capabilities to meet current and future Warfighter objectives.

– Mission and Vision, Robotic Systems Joint Project Office Unmanned Ground Systems Roadmap, July 2009

… develop and field cost-effective USVs to enhance Naval and Joint capability to support: Homeland Defense, the Global War on Terror, Irregular Warfare, and conventional campaigns.

– The USV vision, The Navy Unmanned Surface Vehicle Master Plan, 23 July 2007

… adopt innovative strategies to provide cost effective logistical support …

– Goals and Objectives, US Army Roadmap for UAS 2010-2035

… to harness increasingly automated, modular, globally connected, and sustainable multi-mission unmanned systems resulting in a leaner, more adaptable and efficient Air Force that maximizes our contribution to the Joint Force.

– USAF vision, USAF Unmanned Aircraft Systems Flight Plan 2009-2047

2.1 Future Operational Environment

The strategic environment and the resulting national security challenges facing the United States for the next 25 years are diverse. The United States faces a complex and uncertain security landscape in which the pace of change continues to accelerate. The rise of new powers, the growing influence of nonstate actors, the spread of weapons of mass destruction and other irregular threats, and continuing socioeconomic unrest will continue to pose profound challenges to international order.

Over the next two decades, forces will operate in a geostrategic environment of considerable uncertainty with traditional categories of conflict becoming increasingly blurred. This era will be characterized by protracted confrontation among state, nonstate, and individual actors using violent and nonviolent means to achieve their political and ideological goals. Future adversaries will rely less on conventional force-on-force conflicts to thwart U.S. actions and more on tactics that allow them to frustrate U.S. intentions without direct confrontation.

> The future operating environment will be one of constant and accelerating change. Economic, demographic, resource, climate, and other trends will engender competition locally, regionally, and globally…. State and non-state actors will find new and more deadly means of conducting operations in all domains, to include land, air, maritime, and cyberspace to further their aims … otherwise leveraging land, air, and maritime areas to ensure their freedom of movement and deny it to others..
>
> *– Joint Operational Concept, Irregular Warfare: Countering Irregular Threats*

As technological innovation and global information flows accelerate, nonstate actors will continue to gain influence and capabilities that, during the past century, remained largely the purview of states. Chemical and biological agents will become increasingly more accessible, lethal and sophisticated. Both state and nonstate actors will actively pursue nuclear weapons, sophisticated and/or bioengineered biological agents, and nontraditional chemical agents.

> The next quarter century will challenge U.S. Joint Forces with threats and opportunities ranging from regular and irregular wars in remote lands, to relief and reconstruction in crisis zones, to cooperative engagement in the global commons …. There will continue to be opponents who will try to disrupt the political stability and deny free access to the global commons that is crucial to the world's economy…. In this environment, the presence, reach, and capability of U.S. military forces, working with like-minded partners, will continue to be called upon to protect our national interests.
>
> *– Joint Operating Environment 2010: Ready For Today, Preparing For Tomorrow*

Unmanned systems can help in countering these threats by reducing risk to human life and increasing standoff from hazardous areas.

2.2 DoD's Vision

The DoD, along with industry, understands the effect that innovation and technology in unmanned systems can have on the future of warfare and the ability of the United States to adapt to an ever-changing global environment. DoD and industry are working to advance operational concepts with unmanned systems to achieve the capabilities and desired effects on missions and operations worldwide. In building a common vision, DoD's goals for unmanned systems are to enhance mission effectiveness, improve operational speed and efficiency, and affordably close warfighting gaps.

DoD is committed to harnessing the potential of unmanned systems and strengthening mission effectiveness while maintaining fiscal responsibility. DoD will also work on establishing a complementary relationship between manned and unmanned capabilities while optimizing commonality and interoperability across space, air, ground, and maritime domains.

Open architecture (OA) and open interfaces need to be leveraged to address problems with proprietary robotic system architectures. Standards and interface specifications need to be established to achieve modularity, commonality, and interchangeability across payloads, control systems, video/audio interfaces, data, and communication links. This openness will enhance competition, lower life-cycle costs, and provide warfighters with enhanced unmanned capabilities that enable commonality and joint interoperability on the battlefield.

By prudently developing, procuring, integrating, and fielding unmanned systems, DoD and industry will ensure skillful use of limited resources and access to emerging warfighting capabilities. Pursuing this approach with unmanned systems will help DOD sustain its dominant global military power and provide the tools required by national decision-makers to influence foreign and domestic activities while adapting to an ever-changing global environment. The following quotation captures the breadth of the challenge:

> I speak for the Navy, that unmanned systems have to address all of the domains in which the Navy operates…. We operate on the surface, above the surface, into space, but then we operate below the surface. So when we talk about unmanned and … as we knit all of this capability together and capacity together, it has to take into account that we're operating in all those different domains.
>
> *– Admiral Gary Roughead, Chief of Naval Operations (CNO)*

With the current fiscal environment of constrained budgets, affordability is a factor across the entire acquisition cycle and must be actively engaged by the program managers, users, trainers, and testers to identify problems early, and address cost throughout the life cycle. A dollar saved early results in hundreds of saved dollars compared to problems resolved in production or worse yet during operations and support. While "open systems architecture and data rights" are critical to keeping costs in check, emphasizing the removal of obstacles to competition and the

opportunities in test and evaluation (T&E) to facilitate competitive analysis is equally important to reduce developmental costs.

The assembly line of activity involved in producing unmanned systems must address risk across the life cycle to address the new challenges of testing autonomous functionality in the initial stages, and evaluating the operation and support issues involved in sustainment for increasing reliability, availability, and maintainability. The emphasis on vignettes at a mission level only indirectly emphasizes the increasing need for an evolutionary capability in unmanned systems production that is resilient and responsive to the dynamic situation faced by today's warfighter. New technology, methodologies, and human resourcing are critical for establishing rapid acquisition environments that maximize the potential for unmanned systems production.

2.3 Vignettes

The following vignettes offer examples of the increased capability and flexibility inherent in unmanned systems as DoD continues to field unmanned technologies and integrate resulting systems into its existing force structure. These vignettes are not intended to present an exhaustive list of the possibilities, but rather to present a few examples to illustrate the vision described throughout this Roadmap.

2.3.1 Interoperability Across Domains Vignette, 2030s

Location: Northern Pacific Littoral Areas

Situation: The number and boldness of coordinated, provocative efforts between the Republic of Orangelandia (ROO) and the increasing number of radicalized Islamic nation-states within the tropic zones (± 20° latitude) have increased over the past 15 years. ROO has demonstrated a delivery capability for nuclear intercontinental ballistic missiles, and several radical Islamic nations now openly possess nuclear weapon technology. Although nuclear power's role is expanding, oil remains the energy resource of preference even though gaining access to oil by Western nations has become increasingly constrained and expensive. The United States' gross domestic product (GDP) is being challenged by China.

Scenario: A 50-year-old, former Soviet-era, *Akula* class, nuclear-powered attack submarine sails out of ROO's Molan harbor at night unobserved by Western reconnaissance satellites. Movements of ROO submarines are of high interest due to their rarity (fewer than a dozen occurrences a year) and primarily due to ROO's status as a rogue, nuclear-capable nation-state. The submarine's departure is detected by the underwater surveillance grid, which is monitoring vessel movements in and out of the ROO waters. Ahead of the submarine, a glider unmanned underwater vehicle (UUV) is autonomously

detached from the local network to intercept the faster submarine. Closing to within 50 yards as the submarine passes, the UUV succeeds in attaching a tether to the submarine, which begins pulling the UUV along (see figure right). As the submarine dives below the UUV's operating depth, the UUV adjusts the tether to maintain its position close to the surface. Every three hours, it glides to the surface and transmits a low-power position report.

The position reports are received by an orbiting communications relay, Baton One, an EQ-25 UAS operating at 75,000 ft in the eastern Pacific region. The EQ-25 is an extreme-endurance UAS, capable of operating for two months on station without refueling. As the submarine enters the Sea of Okhotsk and heads toward the North Pacific Ocean, U.S. military commanders are faced with a decision. Despite the advanced battery technology of the UUV, the battery life is finite; therefore, the operators have three courses of action affecting their surveillance operation: (1) continue surveillance by shifting the orbit of Baton One to maintain reception range on the UUV, which will otherwise be lost in 12 hours (2) save the UUV by detaching it when its remaining power is still sufficient for it to recover itself (within three days) or (3) expend the UUV by keeping it attached until its power is exhausted (within six days). Because ROO submarines seldom sortie beyond the littoral seas of northeastern Asia, they decide to shift Baton One's orbit and wait to decide the UUV's fate until the submarine's intent becomes clearer.

By the third day, the submarine is heading toward the mid-Pacific and the Hawaiian Islands. Because the value of the mission exceeds the cost of the asset, the decision is made to expend the low-cost UUV to buy time for a naval anti-submarine warfare (ASW) ship to intercept and track the submarine. The following day, the submarine reverses course. Two days later, the still-attached UUV converts to beacon mode to conserve its dwindling power reserves, Baton One returns to its planned orbit, and the ASW ship turns for Pearl Harbor. A Broad Area Maritime Surveillance (BAMS) UAS, MQ-4C, is launched from Guam to track the beacon. It recovers the beacon's signal and determines that it is stationary. Autonomously descending with its internal airborne sense and avoid (ABSAA) system to maintain "due regard," the BAMS UAS is able to visually acquire the UUV, floating in mid-ocean and no longer attached to the ROO submarine — potentially detached by the submarine's crew. The submarine's position and intent are now unknown.

Ten days later, a weak seismic disturbance is detected 150 miles southeast of Anchorage, Alaska (see map below). Several minutes later, a much more significant event registers 3.5 on the Richter scale. An interagency DoD/homeland defense reconnaissance UAS is launched out of Elmendorf Air Force Base (AFB) and detects a radiation plume emanating near Montague Island at the mouth of Prince William Sound. The UAS maps the plume as it begins spreading over the sound, and a U.S. Coast Guard offshore patrol cutter deployed from Kodiak employs its

embarked unmanned helicopter to drop buoys with chemical, biological, radiological, and nuclear (CBRN) sensors in the Sound and within narrow passes to measure fallout levels. The plume begins to spread over the sound and threatens the city of Valdez. All vessel traffic, mainly oil tankers, transiting in and out of the Sound is stopped, and operations at the oil terminal are suspended. Oil storage facilities at the terminal are quickly filled to capacity, and the flow from Prudhoe Bay is shut down. The port of Valdez, the largest indigenous source of oil for the United States, is effectively under quarantine.

Due to the growing contamination of the local environment, disaster response officials decide to request the support of the military because of their experience both with operations in CBRN zones and with unmanned systems, which are the tools of choice because of the contamination hazards to personnel. The amphibious transport dock ship USS *New York* anchors near an entrance to Prince William Sound and begins operations with its unmanned surface vehicles (USVs) and MQ-8 detachments. An EQ-25 orbit is established over the Sound to ensure long-term, high-volume communication capability in the high-latitude, mountainous region. With data compression technology fielded in the transmitting and relay systems, the EQ-25 is capable of handling all the theater data relay requirements. A USV proceeds to the focus of contamination and lowers a tethered remotely operated vehicle (ROV) to conduct an underwater search for the source. The USV's sonar quickly locates a large object in very shallow water and, on closer inspection by the ROV, images the severely damaged hull of what appears to be an *Akula* class submarine. The hull is open to the sea, and the ROV places temperature gradient sensors on the hull and inserts gamma sensors into the exposed submarine compartments. The Joint Task Force that was formed to manage the disaster quickly determines that the reactor fuel core is exposed to the sea and that the reactor was not shut down and is still critical. Suspicion of the submarine's origin centers on its being from ROO, but all evidence that this vessel is the lost *Akula* submarine is currently circumstantial.

The radiation plume has now encompassed the evacuated town of Valdez, and MQ-8s fly repeated sorties to the town, dock, and terminal areas to deploy UGVs with sensors and collect samples for analysis. Returning USVs and MQ-8s are met and serviced by personnel in hazmat gear and washed down after each sortie. With conditions deteriorating, two unmanned Homeland Defense CBRN barges fitted with cranes, containers, and remote controls arrive from Seattle. USVs are stationed in the narrow straits leading into the Sound with hydrophones to broadcast killer whale sounds to frighten fish outside the Sound away from the contaminated area. Over the next two weeks, with the assistance of U.S and coalition ROVs equipped with cutting torches, grappling fixtures, and operating from USVs, one remotely operated submersible barge is able to work around the clock with impunity against exposure levels to recover the exposed fuel sources and to isolate them in specially designed containers. A second barge similarly retrieves sections of the crippled submarine. Both barges operate with a high degree of autonomy, limiting exposure of personnel to the radioactive contamination.

The UGVs continue monitoring contamination levels and collecting samples, but now also start conducting decontamination of the oil terminal control station and the local power and water facilities. Highly contaminated soil is placed into steel drums, and larger UGVs are used to dig pits and bury contaminated building and pipeline materials. Advanced sensor technology and control logic allows the UGVs to operate around the clock with human operators serving solely in a monitoring function. USVs are used to collect carcasses floating in the Sound and bring

them to shore for disposal. UUVs crisscross the seafloor of the Sound to locate and tag remnants of the submarine for later collection. Unmanned aircraft (UA) fly continuously through the National Airspace System (NAS) at low altitude to monitor and map the declining radiation contours, at medium altitude to map cleanup operations, and at high altitude to relay control commands and data from the nearly one hundred unmanned vehicles at work. Decontamination, refueling, and repair shops have been established in nearby Cordova to service the vehicles and aircraft and on the USS *New York* to service the boats and submersibles. It is the largest coordinated use of international air, ground, and maritime unmanned systems ever conducted.

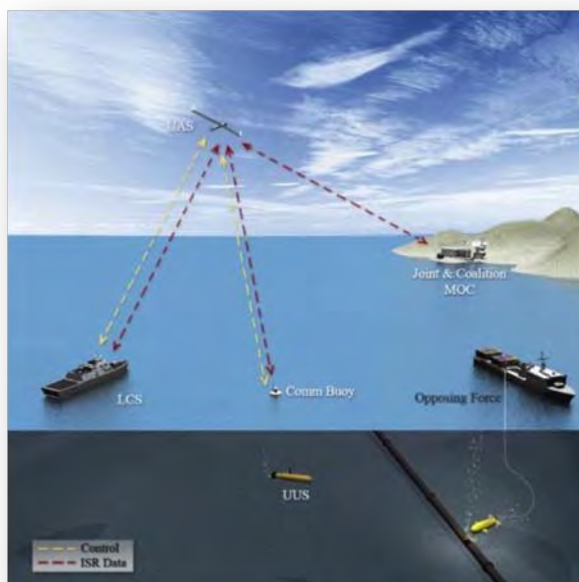
2.3.2 African Maritime Coalition Vignette, 2030s

Location: Gulf of Guinea off the coast of Africa

Situation: An UAS and an UUV, deployed from littoral combat ship (LCS) *Freedom*, are on patrol monitoring the littoral oil infrastructure of a developing nation-state. This nation-state has recently adjusted its geopolitical stance to ally itself militarily and economically with the United States and friendly European governments.

Scenario: The *Freedom*'s UUV in its assigned patrol area detects an anomaly, a remote pipeline welder controlled by an unknown force. The underwater remote welder is positioning itself to intersect a major underwater oil pipeline. Using its organic "smart software" processing capability, the UUV evaluates the anomaly as a possible threat and releases a communications buoy that transmits an alert signal and a compressed data "snapshot" from the UUV's onboard video/acoustic sensor.

The communications buoy's low probability of intercept (LPI) data are relayed via a small tactical unmanned aircraft system (STUAS) to other units in the area and to the Joint Maritime Operations Center (JMOC) ashore. The commander on the LCS directs the UUV and the UAS to provide persistent intelligence, surveillance, and reconnaissance (ISR) and command and control (C2) relay support. Simultaneously, the UAS transmits corroborating ISR data on a suspect vessel near the UUV anomaly. Thanks to a recently fielded, advanced technology propulsion upgrade, the STUAS is able to stay on station for 24 hours before being relieved (see graphic right).



Meanwhile, the JMOC analysts recognize the pipeline welder in the UUV data snapshot as one recently stolen and acquired by rebel antigovernment forces. The JMOC then dispatches an Allied quick reaction force (QRF) via 160^{th} Special Operations Aviation Regiment (SOAR) aircraft and USAF CV-22 Osprey from a nearby airfield. The JMOC retasks a special warfare combatant-craft crewman (SWCC) Mk V to

investigate and neutralize the potential hostile surface vessel controlling the stolen pipeline welder. The SWCC Mk V launches its own small UA to provide a low-level ISR view ahead of its navigation track while providing an LPI secure communications path among the special forces QRF team. The SWCC Mk V's UA provides a real-time common data link (CDL) common operational picture (COP) data stream via the higher altitude UAS to the LCS and JMOC.

The JMOC receives a signals intelligence (SIGINT) alert that the suspect hostile surface vessel is launching a Russian Tipchak, a medium-altitude, long-endurance (MALE) UA. The latest Tipchak variant is a hybrid UA with US-derived systems and avionics. This Tipchak is capable of launching short-range air-to-air missiles (AAMs) or air-to-surface missiles (ASMs). Its host platform, the suspect hostile vessel, has an early warning suite and has probably detected the LCS nearby or visually sighted the SWCC Mk V's UA. An update to the SIGINT alert at the JMOC reveals the Tipchak is being launched for a surveillance sweep and counter-air/counter-UA mission.

Realizing the hostile UA could pose a risk or even jeopardize the QRF, the JMOC commander launches a USAF MQ-1000 UA optimized for air interdiction and ground strike. The MQ-1000 UA, empowered by rules of engagement (ROE) allowing autonomous operation, immediately conducts an air-to-air engagement and neutralizes the Tipchak UA.

The SWCC Mk V's special forces team then conducts a visit, board, search, and seizure (VBSS) on the suspected hostile vessel supporting the UUV pipeline interdictor. Since the threat is neutralized, the unmanned systems update their patrol status, cancel the alert status, and recover or resume their assigned patrol sectors.

2.3.3 Complex Unmanned Systems Test and Evaluation Scenario

As unmanned systems become more complicated, more integrated, more collaborative, and more autonomous, establishing test-driven development constructs and infrastructure for supporting early-onset test and evaluation (T&E) and life-cycle T&E will become increasingly

> "The key to successful acquisition programs is getting things right from the start with sound systems engineering, cost estimating, and developmental testing early in the program cycle. The bill that we are introducing today will require the Department of Defense to take the steps needed to put major defense acquisition programs on a Sound footing from the outset. If these changes are successfully implemented, they should help our acquisition programs avoid future cost overruns, schedule delays, and performance problems."
>
> *–Senator Carl Levin, Chairman, Senate Armed Services Committee*
>
> "The Weapon System Acquisition Reform Act of 2009 is an important step in efforts to reform the defense acquisition process. This legislation is needed to focus acquisition and procurement on emphasizing systems engineering; more effective upfront planning and management of technology risk; and growing the acquisition workforce to meet program objectives."
>
> *–Senator John McCain, Ranking Member, Senate Armed Services Committee*

critical. The Weapon Systems Acquisition Reform Act (WSARA) of 2009 sets the stage for

advancing T&E that will address cost saving through early-on engagement and effective sustainment in facilitating unmanned systems acquisition.

The two previous vignettes have focused on the utility of unmanned systems, but it is also helpful to focus on unmanned systems acquisition. The acquisition of systems with increasing net-centricity and automated functionality will introduce unexpected levels of risk. Systems engineering involves decomposing a design into separable elements, characterizing the intended relationships between them, and verifying the system built to specification operates as intended. The systems engineering "V" represents decomposition and design on the downstroke and integration, verification, and validation on the upstroke. As systems become more complex, the difficulties of addressing the upstroke of the "V" increase. T&E is critical for addressing this risk. The systems engineering of complex systems is gets scrutinized when major problems lead to program delays, cost overruns, and even cancellations. The issues typically lie with unintended and unanticipated interactions between elements that are uncovered only during integration, testing, or once in service. The T&E of manned systems has created optimal strategies for reducing risk in the areas of frequency, performance, support systems, and safety. The primary challenge for today's defense acquisition system is to execute acquisition programs without major schedule delays and cost overruns. Meeting that challenge has been the goal of acquisition reform improvements for decades.

Unmanned systems raise new issues of artificial intelligence, communications, autonomy, interoperability, propulsion and power, and manned-unmanned (MUM) teaming that will challenge current T&E capabilities. These problems will get more serious as systems become more interactive and more automated. Failures often occur at the interfaces between system elements, in many cases, between interfaces thought to be separate. The exponential trends in software and network communications increasingly mean that many elements of a system can now affect one another. The incredible complexity of millions of lines of software requires new approaches for detecting problems earlier in the design phase where cost mitigation is most effective. As systems get much of their functionality from software and multisystem interactions, complexity is no longer separate and distinct. Complexity is about the whole ecosystem, and systems engineering has to become more holistic. Model-based systems engineering, already in use by the software and circuit industries, is augmenting document-driven approaches in important ways. Executable models can be effective conveyors of information throughout a supply chain. Models designed to provide contextual information about the degrees of freedom and the interactions could potentially pass from the Government to the prime supplier and on to second- and third-tier suppliers from early concept through Milestones A, B, and C into the operations and support phase.

Location: DoD T&E Centers Across the World

Situation: In a rapid acquisition support environment, integrated T&E teams work with trainers and the user to accelerate the production of unmanned systems. The model involves industries that must leverage test frameworks to take advantage of Moore's Law advances that are exploitable every 18 months. The same technologies are actually subcomponents in the payload, communication, command system, and remote sensor support systems that currently compose various unmanned system of systems configurations.

Scenario: Warfighters need next-generation system capability to support an 18-month battlespace fielding requirement. The system involves new sensors supporting a remote sensor team. The platform will utilize several new algorithms to mitigate human support functions limited by human reaction time and communication anomalies. The platform will also have new decision algorithms supporting mission functions due to new payload capabilities. The system will use a new communication protocol evaluation system for onboard teams and for ground control teams communicating over a series of relay station and satcom grids. Platform support includes mission-driven T&E to validate autonomous support capabilities enabling nonlethal support functions. This migration will use technology for air traffic management that the Federal Aviation Administration (FAA) and DoD are co-evaluating for the automated notification of an aircraft's position to ground-based controllers as well as to other manned and unmanned aircraft.

The support situation calls for an assessment of the latest Standardization Agreement (STANAG) recovery algorithms in the event of communications link disruption with collaborating manned and unmanned systems supporting a teaming operation. Interoperability tests will be necessary to support several new services and remote service support teams translating data from the payload. The teams will leverage mission information from a variety of semantic databases across the Defense Grid to generate actionable intelligence. A new aspect of this deployment will involve the utilization of both trainers and users interacting with simulators to explore the adequacy of human systems integration algorithms to discover problems for algorithm refinement and problem discovery. Red team T&E technology will expand scenario assessment to provide forecasting without historical data using Bayesian probability models utilizing expert opinions. The T&E system will be designed to determine false positives, false negatives, dynamic limits, and integrity limits regarding mission effectiveness, suitability, survivability, and effectiveness. This wholesale advancement in T&E will result in a tenfold reduction in cycle time and cost.

3 CURRENT STATE

Over the past decade, unmanned systems have played an increasing role in U.S. military operations. DoD uses a vast array of unmanned systems, from underwater to the upper regions of the atmosphere, from the size of a matchbox to the size of a Boeing 737.

These unmanned systems continue to prove their value in combat operations in Afghanistan, where military operations are planned and executed in extremely challenging environments. Adversaries are fighting using increasingly unconventional means, taking cover in the surrounding populations, and employing asymmetric tactics to achieve their objectives. In future conflicts, we must be prepared for these tactics as well as a range of other novel methods, including so-called “hybrid” and anti-access approaches to blunting U.S. power projection. Unmanned systems will be critical to U.S. operations in all domains across a range of conflicts, both because of capability and performance advantages, and the ability for unmanned systems to take greater risk.

As unmanned systems have proven their worth on the battlefield, DoD has allocated an increasing percentage of its budget to developing and acquiring these systems. Table 1 below reflects the budget request allocated to the three unmanned domains: air, ground, and maritime.

Table 1. 2011 President’s Budget for Unmanned Systems ($ Mil)

Unmanned Funding ($ Mil)							
Fiscal Year Defense Prog		FY11	FY12	FY13	FY14	FY15	Total
Air	RDTE	1,106.72	1,255.29	1,539.58	1,440.57	1,296.25	6,638.40
	PROC	3,351.90	2,936.93	3,040.41	3,362.95	3,389.03	16,081.21
	OM	1,596.74	1,631.38	1,469.49	1,577.65	1,825.45	8,100.71
Domain Total		6,055.36	5,823.59	6,049.48	6,381.17	6,510.72	30,820.32
Fiscal Year Defense Prog		FY11	FY12	FY13	FY14	FY15	Total
Ground	RDTE	297.70	271.79	304.78	158.68	157.98	1,190.93
	PROC	20.10	843.24	481.77	426.65	834.17	2,605.93
	OM	207.06	233.58	237.50	241.50	245.96	1,165.60
Domain Total		524.86	1,348.61	1,024.05	826.83	1,238.11	4,962.46
Fiscal Year Defense Prog		FY11	FY12	FY13	FY14	FY15	Total
Sea	RDTE	29.69	62.92	65.72	48.60	47.26	254.19
	PROC	11.93	45.45	84.85	108.35	114.33	364.90
	OM	5.79	4.71	3.76	4.00	4.03	22.28
Domain Total		47.41	113.08	154.32	160.94	165.62	641.37
Fiscal Year Defense Prog		FY11	FY12	FY13	FY14	FY15	Total
All Unmanned	RDTE	1,434.11	1,590.00	1,910.07	1,647.84	1,501.50	8,083.52
	PROC	3,383.93	3,825.62	3,607.02	3,897.95	4,337.53	19,052.04
	OM	1,809.59	1,869.67	1,710.75	1,823.15	2,075.44	9,288.59
Domain Total		6,627.63	7,285.28	7,227.85	7,368.94	7,914.46	36,424.15

Although unmanned systems have experienced widespread growth in funding, current world economic conditions and DoD initiatives necessitate increased efforts and focus toward the acquisition of affordable and convergent systems. DoD must continue to support diverse mission sets and capabilities, but must focus on acquiring Joint and interoperable platforms, systems, software, architecture, payloads and sensors due to today's increasingly austere fiscal environment. In addition, the ability for commanders to take risks with unmanned vehicles depends significantly on their cost. In order to be expendable, which is often the intent of building an unmanned system, the vehicle must be low-cost. The importance of procuring common platforms with core C2 systems cannot be overstated as it will yield enormous collective benefits by reducing training costs, reducing supply chain diversity, improving availability, and offering a cost-effective procurement path by exploiting the benefits of scale and software/technology reuse.

> Eliminate redundancy within warfighter portfolios.
>
> *–Under Secretary of Defense Memorandum for Acquisition Professionals, Better Buying Power, September 2010*

The cost overruns, schedule slips, and sustainability issues of unmanned systems cannot go unnoticed or unanswered. Operational T&E is not sufficient for addressing budget, schedule, and sustainment issues in unmanned systems acquisition. WSARA 2009 guidance set the stage for leveraging developmental T&E as a key factor in T&E strategy to address Milestone A and B test challenges. Unmanned system T&E must not only consider physics effects but other areas that have an effect on algorithm development such as human factors, autonomous functionality, peering, collaboration, and autonomy-driven, red-team-based T&E limit testing. The goal to gradually reduce the degree of human control and decision making required for the unmanned portion of the force structure will mean that autonomous functionality will gradually increase and new ways to test this functionality will be required.

The need to maintain simplicity and overcome bureaucracy in unmanned system acquisition is an ongoing challenge. As these programs transition to acquisition programs, there is a unique opportunity to enable productive process and oversight appropriate to producing safe, suitable, survivable, and effective systems in a rapid acquisition framework.

There is a need to leverage OA and open interfaces to overcome the problems associated with proprietary robotic system architectures. Standards and interface specifications need to be established to achieve modularity, commonality, and interchangeability across payloads, control systems, video/audio interfaces, data, and communication links. Standardization will enhance competition, lower life-cycle costs, and provide warfighters with enhanced unmanned capabilities that enable commonality and joint interoperability on the battlefield.

Addressing factors inhibiting the growth of unmanned systems will provide more interoperability, more autonomy, better artificial intelligence, better communications, human systems integration, training standardization, more propulsion and power options, and better MUM teaming. These factors are addressed through the Joint Capability Integration and Development System (JCIDS) process.

3.1 Requirements Development and Systems Acquisition

There has been substantial growth in unmanned platforms of all sizes and shapes with a corresponding increase in payload numbers and capability. Many of these systems have been rapidly acquired and immediately fielded for warfighter use through the Joint Urgent Operational Needs (JUON) process. JUONs have successfully added significant capability to joint warfighting. While those unmanned systems were rapidly developed to meet the immediate needs of the warfighter in the short term, they have not undergone rigorous requirements review and joint coordination through the normal JCIDS process, to include systems interdependencies and interoperability. Further, their long term affordability, sustainability, and potential to contribute to long term enterprise-wide capability portfolios have not been fully considered. Consequently, they have not received due consideration in the context of broader joint capability areas (JCA) which provide structure and organization to Requirements Development.

DoD is moving toward revision of the JCIDS process which will streamline urgent and deliberate Capability Development to enable requisite timeliness in meeting warfighter needs, while giving important consideration to long term affordability and sustainability. JCIDS is a key supporting process for DoD acquisition and Planning, Programming, Budgeting, and Execution (PPBE) processes. It ensures the capabilities required by the warfighter are identified with their associated operational performance criteria in order to successfully execute the missions assigned. This process allows better understanding of the warfighting needs early in capability development and provides a more comprehensive set of valid prioritized requirements. The Department's acquisition arm can then focus on choosing options to meet well defined requirement capability.

Given today's highly constrained fiscal environment, it is imperative that the Department look at many areas where efficiencies can be gained to create unmanned systems that are both effective and affordable. The DoD will look at capitalizing upon commonality, standardization, and joint acquisition strategies among others. Also, the Department demands these unmanned systems be affordable at the outset and not experience significant cost growth in their development and production evolution. Additionally, it must provide the PPBE process with affordability advice by assessing the development and production lifecycle cost at the outset.

Capability requirements, validated by the JCIDS process, inform prioritization activities in the competition for funding during the PPBE process. The objective of the PPBE process is to provide the best mix of forces, equipment, and support attainable within fiscal constraints according to DoD Directive 7045.14, *Planning, Programming, Budgeting System (PPBS)*. To meet this objective, the PPBE process aims to meet goals established by the President and the Secretary of Defense (SECDEF) in the Strategic Planning and Joint Planning Guidance. In the PPBE process, the Services match available resources (fiscal, manpower, material) against validated requirements to achieve the strategic plan. A key task is to develop a

balanced/affordable capabilities-based Service program objective memorandum (POM). The POM position for the capability to meet a given requirement is reviewed by OSD and the final position becomes the President's Budget.

The Joint Capability Areas (JCAs)[2] are currently the preferred method the Department of Defense uses for reviewing and managing capabilities. The JCA framework provides the structure around which capabilities and capability gaps can be aligned across the Department and across the various portfolios to correlate similar needs, leverage effective solutions, and synchronize related activities. Also, various frameworks, such as the Universal Joint Task List (UJTL), are readily available to aid in identifying and organizing the tasks, conditions and required capabilities.

3.2 Unmanned Systems Applied to Joint Capability Areas

Mapping current and projected unmanned systems against the JCAs provides a sense of the Product Line Portfolio of unmanned systems and how it currently, and could in the future, contribute to the missions of the Department. Each JCA represents a collection of related missions and tasks that are typically conducted to bring about the desired effects associated with that capability. Nine Tier One JCAs are defined, and assessments identified that unmanned systems have the potential to be key contributors for Battlespace Awareness, Force Application, Protection, Logistics, and Building Partnerships. Although assessments have not yet been completed for the Force Support and Net Centric capability areas, missions and tasks in those JCAs receive significant support from unmanned systems as well.

Current technology and future advancements can and will enable single platforms to perform a variety of missions across multiple capability areas. This represents an opportunity for the Department to achieve a greater return on investment. Furthermore, the projections show that there will be opportunities for joint systems to conduct missions for each of the Services, just as there will be situations in which domain conditions or Service missions will dictate unique solutions. Detailed descriptions of each of the systems identified for the capability areas, including specific tasks, performance attributes and integrated technologies can be found at the Unmanned Warfare Information Repository site: **https://extranet.acq.osd.mil/uwir/**. Below are the descriptions for the most relevant JCA.

3.2.1 Battlespace Awareness (BA)

Battlespace Awareness is a capability area in which unmanned systems in all domains have the ability to significantly contribute well into the future to conduct ISR and environment collection related tasks. To achieve this, unmanned systems development and fielding must include the Tasking, Production, Exploitation, and Dissemination (TPED) processes required to translate vast quantities of sensor data into a shared understanding of the environment. There are many ongoing efforts to streamline TPED processing. Applications in this JCA range from tasks such as aerial and urban reconnaissance, which is performed today by Predators, Reapers and Global Hawks in the air and by PackBots and Talons on the ground, to tasks such as Expeditionary Runway Evaluation, Nuclear Forensics, and Special Reconnaissance. In the future, technology will enable

[2] http://www.dtic.mil/futurejointwarfare

mission endurance to extend from hours to days to weeks so that unmanned systems can conduct long endurance persistent reconnaissance and surveillance in all domains. Because unmanned systems will progress further with respect to full autonomy, on-board sensors that provide the systems with their own organic perception will contribute to Battle Space Awareness regardless of their intended primary mission. This capability area is one that lends itself to tasks and missions being conducted collaboratively across domains, as well as teaming within a single domain.

3.2.2 Force Application (FA)

Force Application is another JCA which includes a proliferation of unmanned systems contributing to maneuver and engagement. Today, Predator, Reaper and Gray Eagle UAS are weaponized to conduct offensive operations, irregular warfare, and high value target / high value individual prosecution, and this trend will likely continue in all domains. In the air domain, projected mission areas for UAS include air-to-air combat and suppression and defeat of enemy air defense. On the ground, UGVs are projected to conduct missions such as non-lethal crowd control, dismounted offensive operations, and armed reconnaissance and assault operations. In the maritime domain, UUVs and USVs are projected to be particularly suited for mine laying and mine neutralization missions.

DoD personnel must comply with the law of war, including when using autonomous or unmanned weapon systems. For example, Paragraph 4.1 of DoD Directive 2311.01E, DoD Law of War Program, May 9, 2006, requires that: "[m]embers of the DoD Components comply with the law of war during all armed conflicts, however such conflicts are characterized, and in all other military operations." Current armed unmanned systems deploy lethal force only in a fully human-operated context (level 1) for engagement decisions. For these systems, the decisions both to employ force and to choose which specific target to engage are made by a human. The United States operates defensive systems for manned ships and installations that have human-supervised autonomous modes (level 3), and has operated these systems for decades. For the foreseeable future, decisions over the use of force and the choice of which individual targets to engage with lethal force will be retained under human control in unmanned systems.

3.2.3 Protection

Protection has particular unmanned systems applicability to assist in attack prevention or effects mitigation. Unmanned systems are ideally suited for many protection tasks that are deemed dull, dangerous or dirty. As the future enables greater automation with respect to both navigation and manipulation, unmanned systems will be able to perform tasks such as fire fighting, decontamination, forward operating base security, installation security, obstacle construction and breaching, vehicle and personnel search and inspection, mine clearance and neutralization, sophisticated explosive ordnance disposal, casualty extraction and evacuation, and maritime interdiction. In the Protection JCA teaming within domains and collaboration across domains will likely prevail.

3.2.4 Logistics

The Logistics joint capability area is also ideally suited for employing unmanned systems in all domains to deploy, distribute, and supply forces. Transportation of supplies is an applicable, routine task, particularly suited for unmanned systems in all types of ground terrain.

Maintenance related tasks such as inspection, decontamination, and refueling can be performed by unmanned systems. Munitions and material handling, and combat engineering are ideal tasks that can be allocated to unmanned systems to enhance safety as well as increase efficiency. Additionally, casualty evacuation and care, human remains evacuation, and urban rescue can also be tasks performed by unmanned systems. Unmanned systems will perform Logistics tasks on home station as well as forward deployed.

Table 2. DoD Unmanned Capabilities by Program below is a sample mapping of JCA tasks to the current unmanned inventory and is provided for determining current unmanned systems capabilities.

Table 2. DoD Unmanned Capabilities by Program

AIRCRAFT					
System	Lead Service	Primary JCA	Mission Capabilities	ACAT	Acquisition Status
GROUP 1					
RQ-16B T_Hawk	US Navy	N/A	ISR/RSTA, EOD	Non-ACAT	Other
Wasp	US Air Force	BA	ISR/RSTA	Non-ACAT	Other
RQ-11B Raven	US Army	BA	ISR/RSTA	IV(T)	Production
Puma AE	USSOCOM	N/A	ISR/RSTA, FP	III	Production/Sustainment
GROUP 2					
Scan Eagle	US Navy , US Marines	N/A	ISR/RSTA, Force Protection	Non-ACAT	Other
GROUP 3					
RQ-7B Shadow	US Army, US Marines	BA	ISR/RSTA, C3, Force Protection	II	Production
S 100	USSOCOM	N/A	ISR/RSTA, EW, Force Protection	III	Design &Development
STUAS RQ-21A	US Navy , US Marines	BA	ISR/RSTA, EOD, Force Protection	III	Design &Development
Viking 400	USSOCOM	N/A	ISR/RSTA, EW, Force Protection	III	Design &Development
GROUP 4					
MQ-5B Hunter	US Army	N/A	ISR/RSTA, C3, Log, PS/TCS, FP	N/A	Other
MQ-1C Gray Eagle	US Army	BA	ISR/RSTA, C3, Log, PS/TCS, FP	I D	Production
MQ-1B Predator	US Air Force	BA	ISR/RSTA, PS/TCS, FP	I D	Sustainment
MQ-8B VTUAV	US Navy		ISR/RSTA, ASW, SUW/ASUW,	I C	MS-C
GROUP 5					
MQ-4 BAMS	US Navy		ISR/RSTA, EW, PS/TCS, SUW/ASUW, FP	I D	Design &Development
MQ-9A Reaper	US Air Force	FA	ISR/RSTA, EW, PS/TCS, FP	I D	Production
RQ-4A Global Hawk	US Air Force	BA	ISR/RSTA, C3, PS/TCS	I D	Sustainment
RQ-4B Global Hawk	US Air Force	BA	ISR/RSTA, C3, PS/TCS	I D	Production/Sustainment
MR UAS	US Navy	N/A	TBD	N/A	Concept
UCLASS	US Navy	N/A	TBD	N/A	Concept
MQ-X	US Air Force	FA	ISR/RSTA, PS/TCS, FP	N/A	Concept
Group 4	US Marines	N/A	TBD	N/A	Concept

Table 2. DoD Unmanned Capabilities by Program (continued)

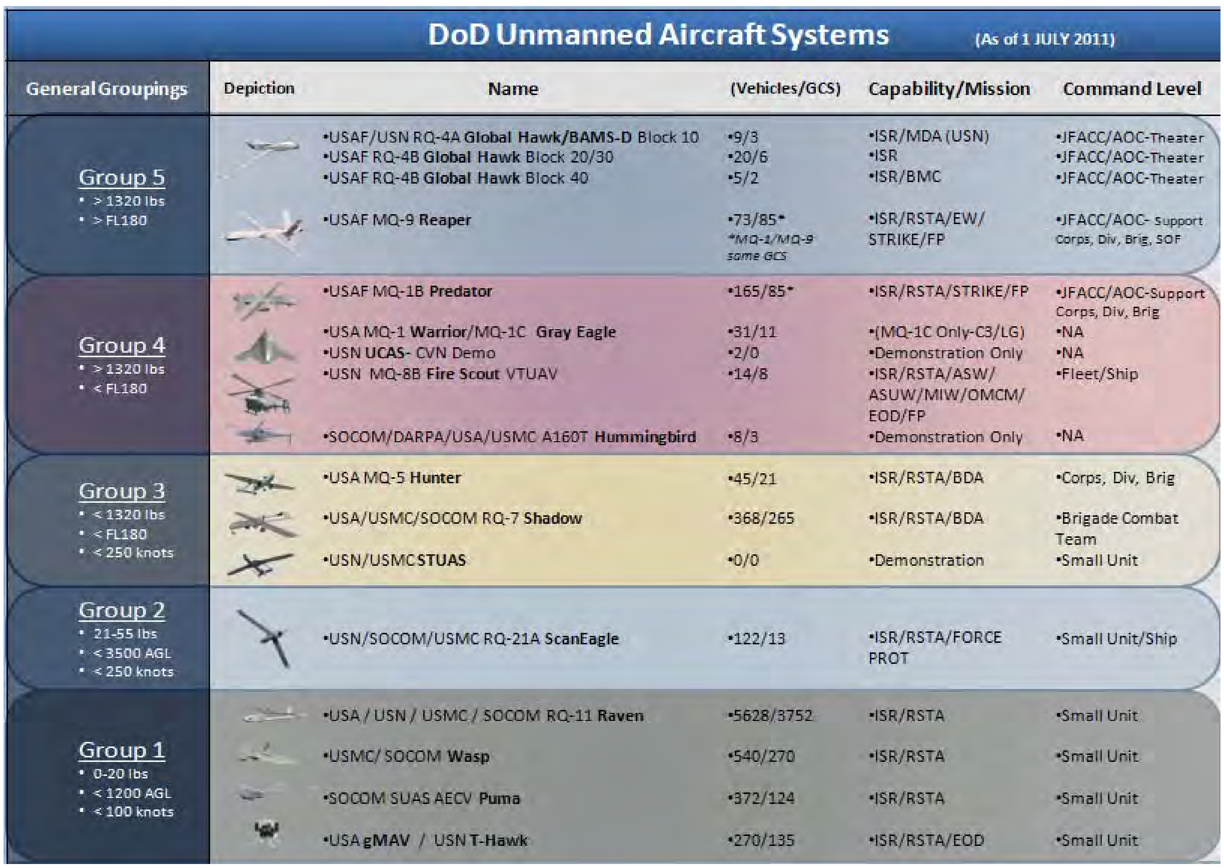
GROUND VEHICLES					
System	Lead Service	Primary JCA	Mission Capabilities	ACAT	Acquisition Status
WHEEL					
MARCbot IV N	US Army	N/A	ISR/RSTA, IED Inv.	Other	Other
Throwbot	US Army	N/A	ISR/RSTA	Other	Other
Mine Area Clearance Equipment (MACE)	US Air Force	N/A	Mine, EOD, FP	Other	Concept
Defender	US Air Force	N/A	FA, FP, Fire	Other	Concept
TRACK					
ISR UGV	US Navy	N/A	ISR/RSTA, Fire Support, EOD	Other	Other
xBot	US Army	N/A	ISR/RSTA, EOD, IED Inv.	Other	Other
PackBot FIDO	US Army	N/A	ISR/RSTA, EOD, IED Inv.	Other	Other
M 160	US Army	N/A	Mine Neutralization	III	Design &Development
RC50 60	US Army	N/A	EOD, Mine Neutralization	Other	Other
Mini EOD	US Army	N/A	EOD	Other	Other
ANDROS HD 1	US Army	N/A	EOD	Other	Other
PackBot EOD	US Army	N/A	EOD	Other	Other
TALON IIIB	US Army	N/A	EOD, route clearance	Other	Other
TALON IV	US Army	N/A	EOD, route clearance	Other	Other
Panther II	US Army	N/A	EOD, Mine Neutralization	Other	Other
MK 1 MOD 0 Robot EOD	US Navy	N/A	EOD	IV	Sustainment
MK 2 MOD 0 Robot EOD	US Navy	N/A	EOD	IV	Sustainment
MK 2 MOD 0 RONS	US Navy	N/A	EOD	IV	Sustainment
All-Purpose Remote Transport System (ARTS)	US Air Force	N/A	Mine, EOD, FP, Fire	Other	Other
F6A ANDROS	US Air Force	N/A	EOD	Other	Other
HD 1	US Air Force	N/A	EOD	Other	Other
IVAN	US Air Force	N/A	EOD, FP	Other	Concept

Table 2. DoD Unmanned Capabilities by Program (continued).

MARITIME CRAFT					
System	Lead Service	Primary JCA	Mission Capabilities	ACAT	Acquisition Status
SURFACE					
Autonomous Unmanned Surface Vehicle (AUSV)	US Navy	N/A	ISR/RSTA	Other	Other
Mine Countermeasures (MCM) Unmanned Surface Vehicle USV	US Navy	BA	MIW/OMCM	Other	Concept
Anti-Submarine Warfare (ASW) Unmanned Surface Vehicle (USV)	US Navy	N/A	ASW	Other	Other
Sea Fox	US Navy	N/A	ISR/RSTA, FP	Other	Other
Remote Minehunting System (RMS), AN/WLD-1(V)1	US Navy	BA	MIW/OMCM	I D	Design &Development
Modular Unmanned Surface Craft Littoral	US Navy	N/A	ISR/RSTA	Other	Other
UNDERWATER					
Sea Stalker	US Navy	N/A	ISR/RSTA	Other	Other
Sea Maverick	US Navy	N/A	ISR/RSTA	Other	Other
Echo Ranger	Commercial	N/A	Insp/ID, Oceanogrpahic Survey	Other	Other
Marlin	Commercial	N/A	Insp/ID, Oceanogrpahic Survey	Other	Other
Surface Countermeasure Unmanned Undersea Vehicle	US Navy	BA	MIW/OMCM	III	Concept
MK18 Mod 2 Kingfish UUV System	US Navy	Protection	SUW/ASUW, MIW/OMCM, Insp/ID	PIP	Production
Surface Mine Countermeasure Unmanned Undersea Vehicle User Operational Evaluation System Increment 2	US Navy	N/A	MIW/OMCM	Other	Other
Surface Mine Countermeasure Unmanned Undersea Vehicle User Operational Evaluation System Increment 1	US Navy	N/A	MIW/OMCM	Other	Other
Battlespace Preparation Autonomous Underwater Vehicle (BPAUV)	US Navy	N/A	MIW/OMCM	Other	Other
HULS	US Navy	Protection	MIW/OMCM, EOD, Insp/ID	Abbr Acq	Production
MK18 Mod 1 Swordfish UUV System	US Navy	Protection	MIW/OMCM, EOD, Insp/ID	Abbr Acq	Sustainment
Large Displacement Unmanned Underwater Vehicle (LDUUV)	US Navy		ASW, ISR, MCM	Other	Concept
MK18 Mod 1 Swordfish UUV System	US Navy		MIW/OMCM, EOD, Insp/ID	Abbr Acq	Sustainment

3.3 Unmanned Aircraft Systems (UAS)

The air domain has received the greatest concentration of visibility as DoD has embraced unmanned technologies. Table 1 depicts that UAS investments will continue to consume a large share of the overall DoD investment in unmanned systems. These efforts have fielded a large number of UAS capable of executing a wide range of missions. Originally, UAS missions focused primarily on tactical reconnaissance; however, this scope has been expanded to include most of the capabilities within the ISR and battlespace awareness mission areas. UAS are also playing a greater role in strike missions as the military departments field multiple strike mission-capable weapon systems for time-critical targeting. Figure 1 below illustrates the variety of platforms in today's force structure.



DoD Unmanned Aircraft Systems (As of 1 JULY 2011)

General Groupings	Depiction	Name	(Vehicles/GCS)	Capability/Mission	Command Level
Group 5 • > 1320 lbs • > FL180		•USAF/USN RQ-4A **Global Hawk/BAMS-D** Block 10 •USAF RQ-4B **Global Hawk** Block 20/30 •USAF RQ-4B **Global Hawk** Block 40	•9/3 •20/6 •5/2	•ISR/MDA (USN) •ISR •ISR/BMC	•JFACC/AOC-Theater •JFACC/AOC-Theater •JFACC/AOC-Theater
		•USAF MQ-9 **Reaper**	•73/85* *MQ-1/MQ-9 same GCS	•ISR/RSTA/EW/ STRIKE/FP	•JFACC/AOC- Support Corps, Div, Brig, SOF
Group 4 • > 1320 lbs • < FL180		•USAF MQ-1B **Predator**	•165/85*	•ISR/RSTA/STRIKE/FP	•JFACC/AOC-Support Corps, Div, Brig
		•USA MQ-1 **Warrior**/MQ-1C **Gray Eagle** •USN **UCAS**- CVN Demo •USN MQ-8B **Fire Scout** VTUAV	•31/11 •2/0 •14/8	•(MQ-1C Only-C3/LG) •Demonstration Only •ISR/RSTA/ASW/ ASUW/MIW/OMCM/ EOD/FP	•NA •NA •Fleet/Ship
		•SOCOM/DARPA/USA/USMC A160T **Hummingbird**	•8/3	•Demonstration Only	•NA
Group 3 • < 1320 lbs • < FL180 • < 250 knots		•USA MQ-5 **Hunter**	•45/21	•ISR/RSTA/BDA	•Corps, Div, Brig
		•USA/USMC/SOCOM RQ-7 **Shadow**	•368/265	•ISR/RSTA/BDA	•Brigade Combat Team
		•USN/USMC **STUAS**	•0/0	•Demonstration	•Small Unit
Group 2 • 21-55 lbs • < 3500 AGL • < 250 knots		•USN/SOCOM/USMC RQ-21A **ScanEagle**	•122/13	•ISR/RSTA/FORCE PROT	•Small Unit/Ship
Group 1 • 0-20 lbs • < 1200 AGL • < 100 knots		•USA / USN / USMC / SOCOM RQ-11 **Raven**	•5628/3752	•ISR/RSTA	•Small Unit
		•USMC/ SOCOM **Wasp**	•540/270	•ISR/RSTA	•Small Unit
		•SOCOM SUAS AECV **Puma**	•372/124	•ISR/RSTA	•Small Unit
		•USA **gMAV** / USN **T-Hawk**	•270/135	•ISR/RSTA/EOD	•Small Unit

Figure 1. DoD UAS

As the number of fielded systems has expanded, flight hours have dramatically increased as depicted in Figure 2.

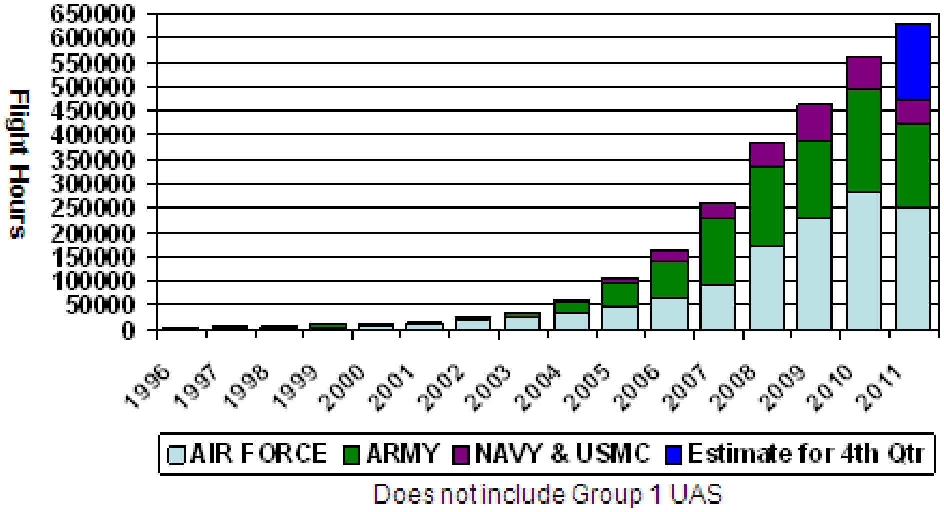


Figure 2. UAS Flight Hours (1996–Present)[3]

In 2009, DoD completed almost 500,000 UAS flight hours just in support of Operation Enduring Freedom and Operation Iraqi Freedom. In May 2010, unmanned systems surpassed one million flight hours and in November 2010 achieved one million combat hours. As these systems continue to demonstrate their value, this number will continue to grow.

> … remotely piloted vehicles have flown more than 21,000 sorties so far this year, already surpassing the roughly 19,000 drone flights last year.
>
> *– "U.S. Uses Attacks to Nudge Taliban Toward a Deal," New York Times, October 15, 2010.*

3.4 Unmanned Ground Systems (UGS)

Since operations in Iraq and Afghanistan began, DoD has acquired and deployed thousands of UGS. These systems support a diverse range of operations including maneuver, maneuver support, and sustainment. Maneuver operations include closing with and neutralizing the enemy using speed and firepower. Maneuver support missions include mitigating natural and artificial obstacles and hazards. Sustainment missions leverage maintenance and support UGVs associated with combat services support.

Approximately 8,000 UGVs of various types have seen action in Operation Enduring Freedom and Operation Iraqi Freedom. As of September 2010, these deployed UGVs have been used in over 125,000 missions, including suspected object identification and route clearance, to locate and defuse improvised explosive devices (IEDs). During these counter-IED missions,

[3] Updated 30 June 2011.

Army, Navy, and USMC explosive ordnance teams detected and defeated over 11,000 IEDs using UGVs, such as the one depicted in Figure 3.

Figure 3. Talon Ordnance Disposal Robot Preparing to Unearth Simulated IED

The lessons collected on the battlefield must be translated into programs that can be sustained. The rapid fielding and proliferation of unmanned systems and the subsequent battlefield modernization they provided have met the mission, but resulted in configuration and maintenance challenges. These ground systems continue to provide tremendous benefit to the ground commander, but improvements in user interfaces, reliability, survivability, and advances in 360° sensing, recording fidelity, and CBRN and explosive detection are required to meet the challenges anticipated in future conflicts. Figure 4 shows the UGS Family of Systems (FoS).

On Gordon's (UGV) final days, he was launched out of the truck and was searching an intersection for a possible deep buried IED. As he was on his way to the intersection, the IED was detonated about 10 ft from his location. Still functioning, he continued to search the area. On the opposite side of the road, another IED was detonated and had turned him upside down. Everything was still working until a fire fight started.

Gordon took 7 rounds to the underside and was done for the day. I took him to the robot shop for repair. It took 3 days. When he was returned to us, I put him back in the truck to get him back on duty. But this was shortly lived as he was searching a gate at a house for possible booby-traps that detonated directly next to him. Gordon was mangled beyond repair. Now his replacement "Flash" is here to finish his job.

-- Insight from an End User: *"Gordon" TALON Defeats IEDs and Saves Lives in Baghdad*, submitted by an EOD operator, summer 2007, Iraq.

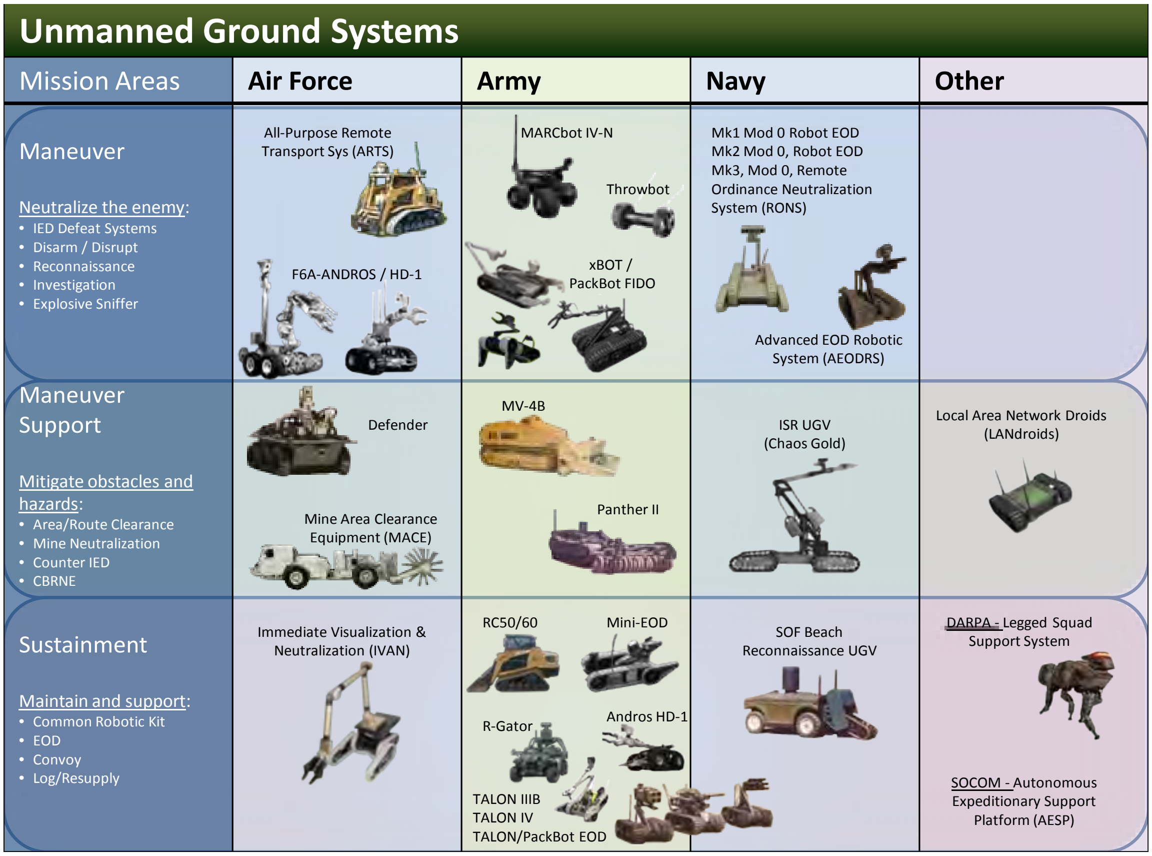


Figure 4. UGS FoS

3.5 Unmanned Maritime Systems (UMS)

Over 90% of the information, people, goods, and services that sustain and create opportunities for regional economic prosperity flow across the maritime domain. With emerging threats such as piracy, natural resource disputes, drug trafficking, and weapons proliferation, a rapid response capability is needed in all maritime regions. DoD continues to expand the range of missions supported by unmanned systems in the maritime domain. A recent study concluded

> USVs, along with UUVs, will have an important role in the conduct of MCM [mine countermeasures] as they are particularly well suited for the 'dirty - dull - dangerous' tasks that MCM entails. They provide persistence, which permits significant mine hunting and sweeping coverage at lower cost by multiplying the effectiveness of supporting or dedicated platforms. Additionally, they provide the potential for supporting an MCM capability on platforms not traditionally assigned a mine warfare mission.
>
> – *USV mission descriptions, The Navy Unmanned Surface Vehicle Master Plan, 23 July 2007*

that unmanned maritime systems "have the potential to provide critical enabling capabilities for current NATO [North Atlantic Treaty Organization] maritime missions that can improve Alliance security and stability".[4]

Like UAS and UGS, UMS have the potential to save lives, reduce human risk, provide persistent surveillance, and reduce operating costs. UMS priority missions are listed below.

UMS PRIORITY MISSIONS

Mine Countermeasures (MCM)

Anti-Submarine Warfare (ASW)

Maritime Domain Awareness

Maritime Security

UMS can be defined as unmanned vehicles that displace water at rest and can be categorized into two subcategories: unmanned underwater vehicles (UUV) and unmanned surface vehicles (USV). USVs are UMS that operate with near-continuous contact with the surface of the water, including conventional hull crafts, hydrofoils, and semi-submersibles.[5] UUVs are made to operate without necessary contact with the surface (but may need to be near surface for communications purposes) and some can operate covertly.

The use of UMS is not new. After World War II, USVs were used to conduct minesweeping missions and test the radioactivity of water after each atomic bomb test. Another example occurred during the Vietnam War in an area south of Saigon, where remotely controlled USVs conducted minesweeping operations. More recently, UUVs conducted mine-clearing activities during Operation Iraqi Freedom in 2003. A complementary suite of UMS serve as the foundation for MCM operations from the Littoral Combat Ship (LCS) and small diameter UUVs are currently the main mine detection capability for ports & harbor and in the Very Shallow Water zone.

At a recent Science and Technology Conference hosted by the Office of Naval Research, Chief of Naval Operations (CNO) Admiral Gary Roughead made a number of statements expressing UMS goals for the Department of the Navy. Solving the power consumption problem would be the "one thing" CNO would most like to see the Navy's scientists accomplish.[6] Rear Admiral Nevin Carr, Chief of Naval Research, explained the current efforts in filling the needs in this unmanned maritime area and went on to describe where and how this technology might be applied in the future: "Two options are under exploration: fuel-cell technologies and radioscope thermoelectric generators that can provide low amounts of power for very long periods of time. We might start thinking about setting up drone refueling stations. You might deploy a remotely manned underwater generator that sits on the bottom in a secure area, which is a secure location where your forward-deployed vehicles might come back and recharge."

Figure 5 illustrates the variety of platforms and maritime missions supporting today's operations by UMS and those planned for operation in the near future. They have the potential

[4] The Combined Joint Operations from the Sea Centre of Excellence (CJOS/COE) Study (2009) for Maritime Unmanned Systems (MUS) in NATO, 8 December 2009.

[5] Consistent with Navy USV Master Plan, 2007.

[6] Ackerman, Spencer, Navy Chief Presses Nerds to Power Up Undersea Drones, Danger Room, Wired.com, 8 November 2010.

for even greater integration, especially UUVs, to the point of assisting the current submarine and surface fleet in replacing fixed underwater sensor grids; using UUVs and distributed netted sensors to expand our submarine's sphere of influence; and weaponizing UUVs.

However, there are currently limitations to realizing the full potential of UMS:

- Endurance
- Underwater C2 and deconfliction
- Survivability in an unforgiving environment
- Launch and recovery
- Communication technology for dynamic tasking, querying, and data dissemination

These challenges are areas for further technical exploration. Despite these challenges, the future for UMS is very promising. Building on the experience and contribution from this first generation of fielded UMS, the shift is underway from UMS merely serving as an extension of the sensor systems of manned ships and submarines into an integrated FoS to provide full mission capabilities with increased autonomy.

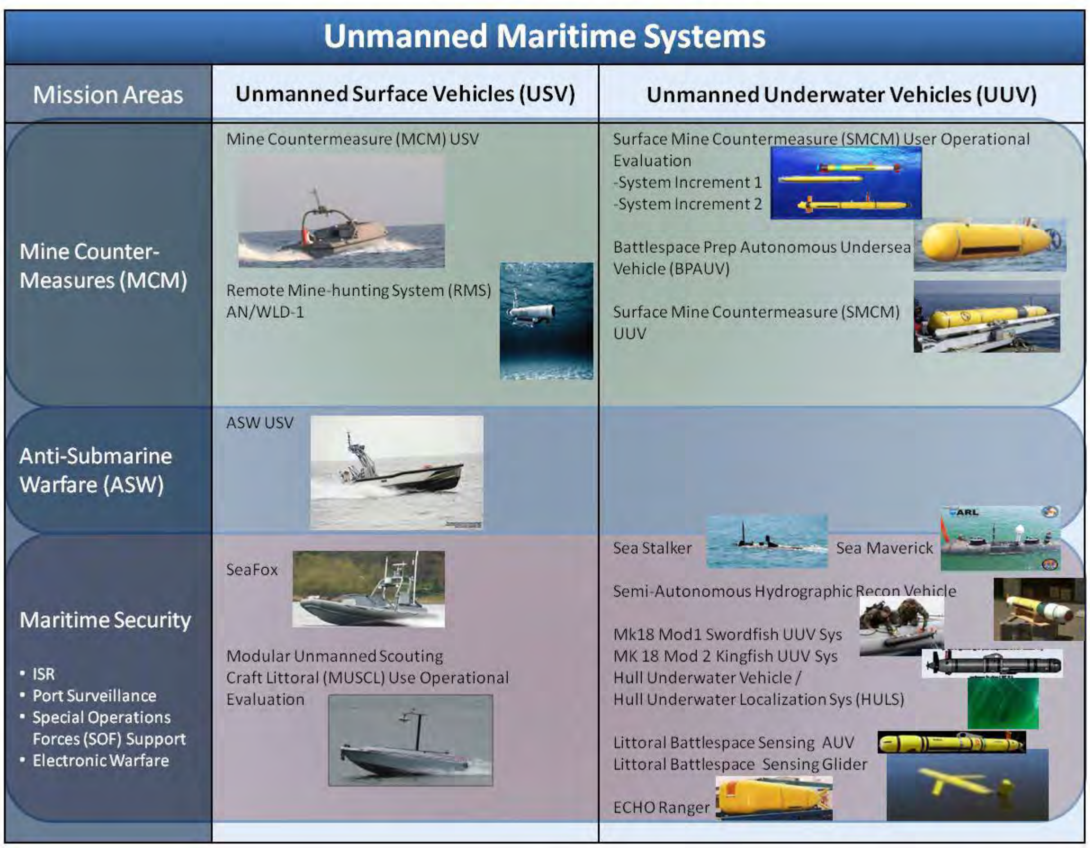


Figure 5. DoD UMS FoS

3.6 Challenges for Unmanned Systems

The number of fielded systems and the range of missions supported by unmanned systems continue to grow at a dramatic rate. As DoD steers a path toward the vision described in Section 2, the challenges listed on the right must be overcome in order to realize the full potential offered by unmanned systems. The following subsections summarize these challenges and the remainder of this document provides details and future goals for dealing with each challenge.

3.6.1 Interoperability

To maximize the potential of unmanned systems, the systems must be capable of operating seamlessly with each other and with manned systems across the air, ground, and maritime domains. System interoperability is critical in achieving these objectives and requires the implementation of mandated standards and Interoperability Integrated Product Team (I-IPT) profiles. Properly implemented, interoperability can serve as a force multiplier, improve joint warfighting capabilities, decrease integration timelines, simplify logistics, and reduce total ownership costs (TOC). One of the most powerful tools in maximizing interoperability and achieving these objectives is the adoption of the open systems architecture concept.

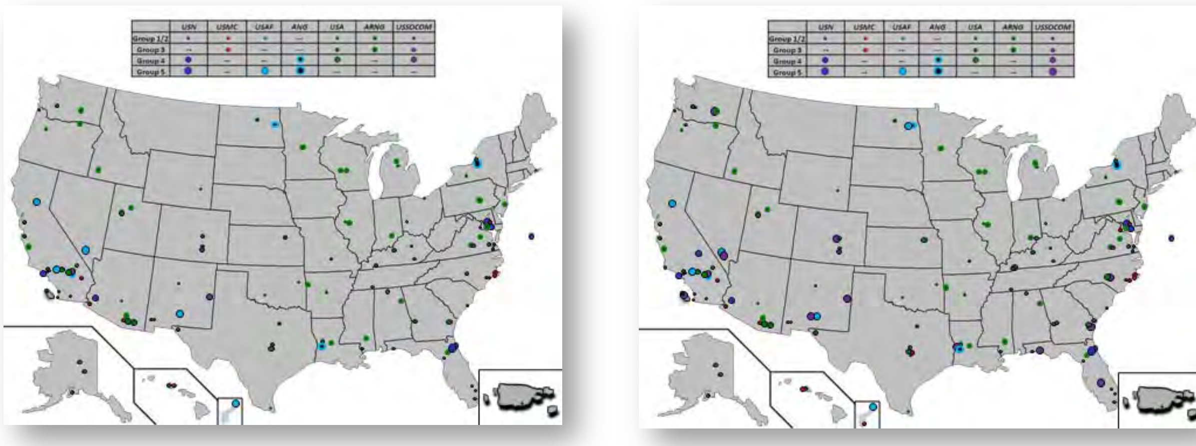
3.6.2 Autonomy

The rapid proliferation of unmanned systems and the simultaneous operation of manned and unmanned systems as unmanned systems expand into additional roles have created a manpower burden on the Services. With limited manpower resources to draw upon, the Services are seeking ways to improve the efficiency of operations. For instance, introducing a greater degree of system autonomy will better enable one operator to control more than one unmanned system, and has the potential to significantly reduce the manpower burden. Additional benefits are greatly reducing high bandwidth communication needs and decreasing decision cycle time. Similar efficiencies can be gained by automating the tasking, processing, exploitation, and distribution (TPED) of data collected by unmanned systems. Autonomy can help extend vehicle endurance by intelligently responding to the surrounding environmental conditions (e.g., exploit/avoid currents) and appropriately managing onboard sensors and processing (e.g., turn off sensors when not needed). Implementing a higher degree of autonomy faces the following challenges:

- Investment in science and technology (S&T) to enable more capable autonomous operations
- Development of policies and guidelines on what decisions can be safely and ethically delegated and under what conditions
- Development of new Verification and Validation (V&V) and T&E techniques to enable verifiable “trust” in autonomy

3.6.3 Airspace Integration (AI)

The rapid increase in fielded UAS has created a strong demand for access within the NAS and international airspace. The demand for airspace to test new systems and train UAS operators has quickly exceeded the current airspace available for military operations. Figure 6 shows the projected number of DoD UAS locations in the next six years, many without access to airspace compatible for military operations under the current regulatory environment.



2011 **2017**

Figure 6. Representative DoD UAS Locations from 2011 to 2017.

NAS access for UAS is currently limited primarily due to regulatory compliance issues and interim policies. DoD UAS operations conducted outside of restricted, warning, and prohibited areas are authorized only under a (temporary) Certificate of Waiver or Authorization (COA) from the FAA. The COA process is adequate for enabling a small number of flights, but does not provide the level of airspace access necessary to accomplish the wide range of DoD UAS missions at current and projected operational tempos (OPTEMPOs). This constraint will only be exacerbated as combat operations in Southwest Asia wind down and systems are returned to U.S. locations.

3.6.4 Communications

Current unmanned systems operations involve a high degree of human interaction with the systems via various means for C2 and transmission of operational data. Protection of these communication links and the information flowing through them is critical to these operations. As the number of fielded systems grows, communications planners face challenges such as communication link security, radio frequency spectrum availability, deconfliction of frequencies and bandwidth, network infrastructure, and link ranges. Intelligent means of data parsing is needed to enable TPED and counter communication challenges.

3.6.5 Training

The rapid proliferation of numbers and types of UAS in response to wartime demand coupled with an expected redeployment of forces back to a peacetime footing will result in continuation training greater than what has been required in the past. This has caused pause to examine UAS training and to develop an overall strategy. At present, due to high demand for UAS assets in real world contingencies, most day-to-day, continuation training is accomplished under in-theater combat conditions. At the same time, disparate efforts by a number of organizations across the Department are underway to try to address UAS training requirements. As UAS forces drawdown in theater and redeploy, the Services will require comprehensive continuation and Joint force training in the peacetime environment at UAS bed-down and selected Joint training locations.

3.6.6 Propulsion and Power

The dramatic increase in the development and deployment of unmanned systems across the entire spectrum of air, ground, and maritime missions has led to a concurrent increase in the demand for efficient, powerful, often portable, and logistically supportable solutions for unmanned system propulsion and power plant requirements. As these systems continue to demonstrate their value, operators want them to function longer without refueling and to do more tasks; these demands tax the internal power sources. The laboratories of the military Services and industry are focusing their efforts to find efficient solutions to the demand for improved propulsion and power plants. Regardless of energy source, total vehicle design, from materials used to autonomous response to the physical environment, needs to be considered up front to maximize endurance.

3.6.7 Manned-Unmanned (MUM) Teaming

MUM teaming refers to the relationship established between manned and unmanned systems executing a common mission as an integrated team. U.S. military forces have demonstrated early progress in integrating unmanned systems within the existing manned force structure, but much more needs to be done to achieve the full potential offered by unmanned technology. Improving MUM teaming is both a technology challenge (such as connecting the systems) and a policy challenge (such as establishing the rules of engagement for operating semi-autonomous unmanned with manned systems).

4 INTEROPERABILITY

4.1 Overview

There is a clear benefit for warfighters to be able to seamlessly command, control, communicate with, exploit and share sensor information from unmanned systems across multiple domains. The Unmanned Systems Interoperability Initiative (UI2) led by the OSD UAS Task Force is in the process of developing an overarching strategy for increasing unmanned systems interoperability, with the long-range vision of producing a strategy that can be leveraged across the full spectrum of both unmanned and manned systems. DoD's goal is to move from Service/Agency-unique, stand-alone capabilities toward substantially improved interoperability standards that lead to an improved collaborative operational environment.

> Lack of UAV interoperability has had a real-life impact on U.S. operations … there have been cases where a Service's UAV, if it could have gotten data to another Service, another component, it may have provided better situational awareness on a specific threat in a specific area that might have resulted in different measures being taken.
>
> *– Dyke Weatherington (PSA/UW)*

4.2 Functional Description

Interoperability is the ability to operate in synergy in the execution of assigned tasks.[7] Properly implemented, it can serve as a force multiplier, improve warfighter capabilities, decrease integration timelines, simplify logistics, and reduce TOC. DoD Directive (DODD) 5000.1 establishes the requirement to acquire systems and FoSs that are interoperable.[8] DoD's unmanned systems will need to demonstrate interoperability in a number of areas:

- *Among similar components of the same or different systems.* The plug-and-play use of different sensors on an unmanned vehicle.
- *Among different systems of the same modality.* An open common ground control station (GCS) architecture for multiple, heterogeneous unmanned vehicles.
- *Among systems of different modalities.* The ability of air, ground, and maritime vehicles to work cooperatively.
- *Among systems operated by different Military Departments under various CONOPS and TTP, i.e., in joint operations.* Joint service systems working in concert to execute a common task or mission.

[7] Definition found in Joint Publication (JP) 1-02, Department of Defense Dictionary of Military and Associated Terms, 12 April 2001 (as amended through 17 March 2009).
[8] DODD 5000.1, Enclosure 1, paragraph E1.10.

- *Among systems operated and employed by coalition and allied militaries under the governance of various concepts of employment (CONEMPs), TTPs, e.g., in multinational combined operations or NATO STANAGs.* The ability of coalition and allied systems to work in concert to execute a common task or mission based on predefined roles and responsibilities.
- *Among military systems and systems operated by other entities in a common environment.* The ability of military UAS to share the NAS and international airspace with commercial airliners and general aviation.
- *Among systems operated by non-DoD organizations, Allies, and coalition partners, i.e., in combined operations.* The ability of assets from organizations such as Customs and Border Protection (CBP) and Department of Homeland Security (DHS) to coordinate, interoperate, and exchange information with DoD assets of the same modality and same model.

> The interoperability goal for Unmanned Systems is an ability to provide data, information, material, and services to and accept the same from other systems, units, or forces … and to use the exchanged data, information, material, and services to enable them to operate effectively together.

The Joint Unmanned Aircraft Systems Center of Excellence (JUAS COE)[9] maintains the Joint CONOPS for UAS, which provides a joint vision for the operation, integration, and interoperability of UAS and touches on several of the areas mentioned above. Figure 7 illustrates joint, cross-domain interoperability.

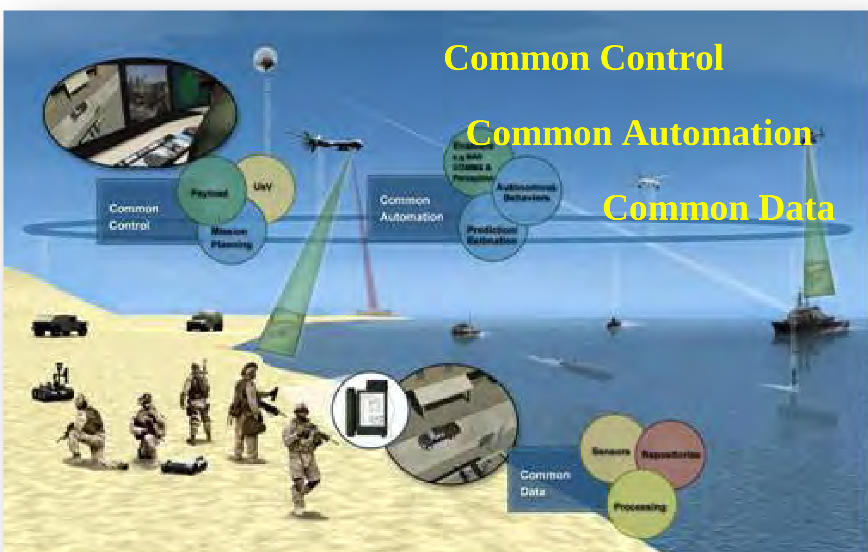


Figure 7. Joint Cross-Domain Interoperability.

[9] JCOE is being disbanded June 2011 and its tasks are being transferred to the Joint Staff.

4.3 Today's State

The historical approach to software and hardware acquisition relied on dedicated design for each system to accomplish a specific mission or capability. This approach may be optimal for a single system, but it unfortunately produces a collection of discrete, disjointed solutions with significant functional overlap and no method to exploit common components of each system.

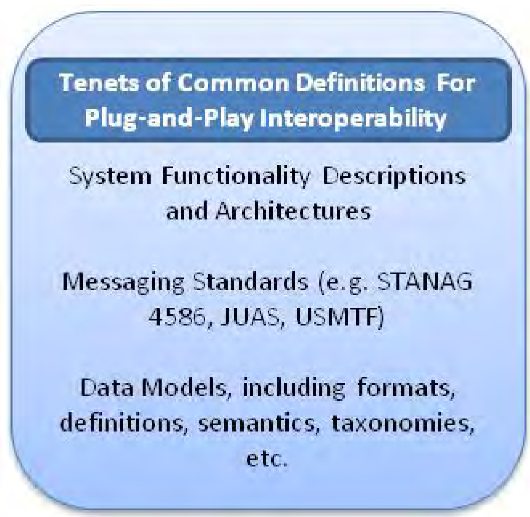
Open architecture (OA) facilitates interoperability between systems by effectively leveraging the following concepts:

- Common capability descriptions in system requirements
- Common, open data models, standards, interfaces, and architectures in system design
- Common components in system acquisition strategies

OSD defines OA as a multifaceted strategy providing a framework for developing joint interoperable systems that adapt and exploit open-system design principles and architectures. This framework includes a set of principles, processes, and best practices that:

- Provide more opportunities for competition and innovation
- Rapidly field affordable, interoperable systems
- Minimize total ownership cost
- Optimize total system performance
- Yield systems that are easily developed and upgradeable
- Achieve component software reuse[10]

These (predominantly) acquisition issues are aided by a solid framework for software, component, and systems interoperability.



Traditionally, efforts have focused on system functionality descriptions, with interoperability focused at the messaging layer (e.g., the Joint Architecture for Unmanned Systems (JAUS) and STANAG 4586) to achieve standards-based interoperability. However, the tenets of common definitions and understanding listed on the left are required to achieve a true plug-and-play level of interoperability in which software capabilities from multiple vendors can be developed and integrated into a single system, supporting the exchange, interpretation, and action on data from other systems.

Through implementation and program-level

[10] Terms and Definitions, Defense Acquisition University, https://acc.dau.mil/CommunityBrowser.aspx?id=22108.

adoption of these three tenets, DoD intends to address the issue of single proprietary vendor dependency within the acquisition system and improve conditions allowing for full competition.

4.4 Problem Statement

Unfavorable Characteristics of Current Approach

- Lack of re-usability, resulting in RDT&E dollars being inefficiently utilized on repeated development of similar technology for different platforms.
- Difficulty of upgrading and enhancing capability due to the proprietary nature of UxVs.
- Inability to leverage research and development conducted at small businesses.
- Reliance on large prime vendors and vertical integrators who have little motivation for controlling and managing schedule.

Over the last decade, the DoD has achieved great successes from the use of unmanned systems for both peacetime and wartime operations. These successes led to a significant increase in the number of unmanned systems planned and procured, and the future looks to see an exponential increase in the quantity and diversity of unmanned systems applications. Traditionally, each unmanned system was procured as a vertically integrated, vendor-proprietary solution, consisting of the vehicle system, control station, communications channels, and encryption technologies. These single-system variants were typically "closed" systems utilizing proprietary interfaces. Development of the entire system was conducted in parallel with close interdependencies between components and procured as a whole through the platform prime contractor. As the number of new unmanned systems programmed in the Service budgets increased, the magnitude of RDT&E requirements for development skyrocketed. In addition to cost, this approach resulted in a number of unfavorable acquisition and growth characteristics that impeded progress as depicted above. Further, silence about the lack of interoperability and standards failed to foster dialog on how to overcome them. Over time, this resulted in an inhibition to innovation; increased vulnerability to threats where attacks on common attributes can impact multiple systems; increased complexity to systems engineering, development, and test; increased upfront costs; increased costs to system upgrades that cannot be made without changes to the interoperable dependencies of multiple systems; and budgeting protocols that treat interservice and coalition interoperability as fiscal trade-space.

These issues have significantly hampered unmanned systems acquisition activities. However, urgent wartime needs dictated that such concerns be relegated to the background, in the interest of rapid initial deployment. As the unmanned systems industry matures, however, the acquisition process must evolve in parallel. Addressing and enabling interoperability within unmanned systems will help accomplish this goal.

4.5 The Way Ahead

The technical approach to achieve the interoperability vision leverages the tight connection between interoperability and OAs, and consists of several elements. Each of the following elements is required, and none is sufficient in its own right to implement an OA:

- Development of a standard data model and service definitions that support OA concepts.
- Development of multiple repositories of models, software components, interface standards, and infrastructure services that can be used across the Services to extend, adapt, and compose unmanned systems and support software component reuse. These repositories should encourage the use of commercial, off-the-shelf (COTS) solutions where available, and are not intended to be "single point bottlenecks" as other efforts have been in the past. The goal is to provide multiple collection points across the Services for best practices, interfaces, and implementations.
- Collaboration among Government, industry, and academia to extend and manage the repositories and to validate components.
- Migration of current and developing systems to the OA approach.

To meet current interoperability standards, DoD will rely more heavily on spiral and incremental development initiatives ensuring services are compliant with these standards.

4.5.1 Open Architecture (OA)

OA utilizes a common set of interfaces and services; associated data models; robust, standard data busses; and methods for sharing information to facilitate development. OA involves the use of COTS components with published, standard interfaces, where feasible, at all levels of system design. This approach avoids proprietary, stove-piped solutions that are vendor-specific and enables innovation to be better captured and integrated into systems design. The OA approach allows for expanded market opportunities, simplified testing and integration, and enhanced reusability throughout the program life cycle. The Navy's Cruiser Modernization Program is one such effort.

The OA process encourages innovation, allows information sharing among competitors, and rewards Government and industry for this collaboration. It allows programs to include small businesses in systems acquisition activities as a valuable, affordable, and innovative source of technologies and capabilities. The result is a better product.

DoD unmanned systems consist of a wide range of programs, architectures, and acquisition approaches. To create a common framework for development and acquisition, DoD adopted principles of OA and service-oriented architecture (SOA). While the OA is the contracting, architecture, and business process methodology used to develop and acquire systems, a SOA is a specific way of designing software, in a standardized architecture, that uses interchangeable and interoperable software components called *services*. When coupled together, the result is a business approach to acquiring software developed within a common engineering construct that promotes reuse, cost reduction, competition, growth opportunity, expandability, innovation, and interoperability among similar systems.

SOA provides a set of principles or governing concepts that are used during the phases of systems development and integration. This type of architecture attempts to package functionality as interoperable services within the context of the various business domains that use it. SOAs increase functionality by incorporating new services, which are developed separately but integrated within the system's common framework as a new capability. Their interfaces are independent of application behavior and business logic, and this independence makes the interfaces agile in supporting application changes and enables operations across heterogeneous software and hardware environments.

Programs and efforts to date have strongly tied together unmanned systems capability requirements and definitions, along with underlying technology selections. In recognition of the rapidly changing technology, unmanned systems architectures would benefit strongly from being defined at a platform-independent model (PIM) level, which is devoid of technology dependence.

The PIM level allows for definition of domains, software components, interfaces, interaction patterns, and data elements without flattening them to a specific set of computing, communications, and middleware technologies. Aside from enabling technology-independent design, this approach, as formalized in model-driven engineering principles, fosters interoperability.

At a minimum, a common set of interfaces and messaging standards is required for interoperability. Without a common semantic understanding of what data represent, there is significant opportunity for lack of interoperability, even if messages are correctly parsed and interfaces are followed. Therefore, a key final aspect is the recognition that data modeling is a separate, core aspect for defining interoperable systems. This aspect includes specifying definitions, taxonomies, and other semantic information to ensure there is a common understanding about what information a specific data item imparts.

This approach supports the involvement of multiple organizations in the development of one or more services, and results in increased innovation, flexibility, and improved performance. SOAs, however, constitute only one approach to implementation of OAs. Certain programs may not need SOAs. The program manager will determine the correct architecture to implement. Regardless of whether SOA approach is used, DoD has mandated an OA approach in software development. The program manager will be responsible for implementing an environment that will support OA in both programmatic and technical areas.

4.5.2 Service Repositories

DoD recognizes that there is rarely a one-size-fits-all solution to the challenging problem of software and service reuse. However, service repositories fill a growing need within DoD for commonality, reuse, and reduced duplication of effort, all of which aid interoperability by leveraging common interfaces. Programs will have access to the service repositories for their use in planning and implementation. In addition, programs will be encouraged to contribute services (within Government Data Rights constraints) to the repositories for future reuse. Where programs have requirements that cannot be met by software within the repositories, existing

services may be extended to add functionality, and this approach should result in cost savings over the creation of brand new capabilities.

Constructing such repositories requires a commitment to OA, along with the adoption of existing and upcoming standards (e.g., SAE JAUS, STANAG 4586, UCS), so that a common framework exists with which to develop services. In addition, tools are necessary to ease adoption, reduce learning curves, and provide validation and certification capabilities. See Figure 8.

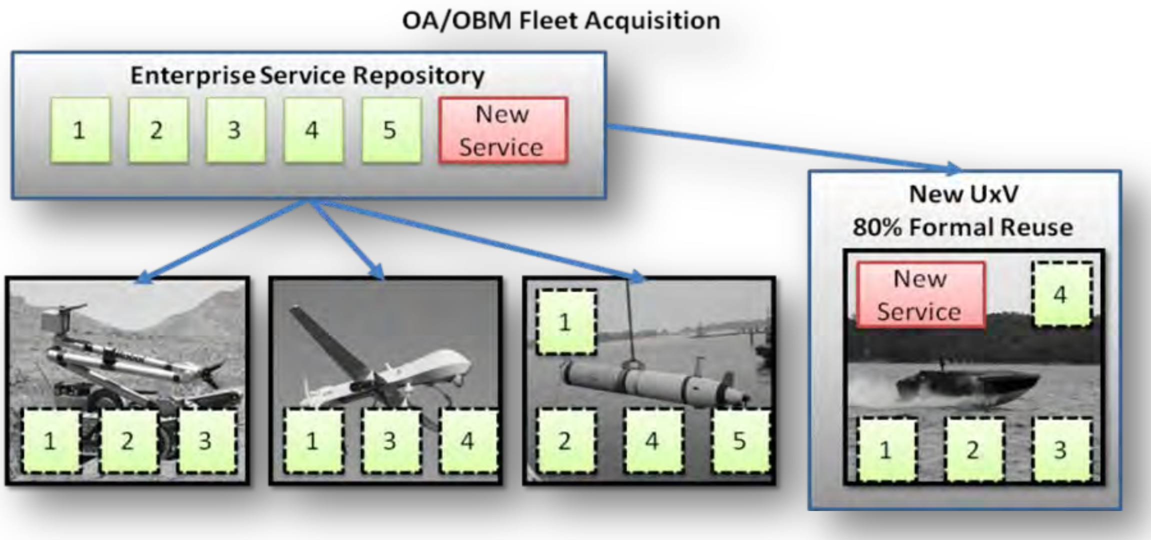


Figure 8. Cross-Domain Service Reuse Through an Enterprise Service Repository.

OA allows components to be developed once rather than redeveloped for each warfare area or mission. OA exploits software reuse and open interfaces to ensure unnecessary costs are not incurred in the redevelopment of core software. The OA approach described in this section utilizes collaboration among Government, industry, and academia to comply with principles of modularity, reusability, interoperability, affordability, and competition to develop reusable products.

Through implementation of the OA approach, DoD will develop and establish a domain service portfolio management (DSPM) repository for new acquisition and in-service programs. This repository will contain program-related software services information including standard architectures, design guidelines, service interfaces, and specifications for designing new systems or modifying existing systems. Programs will be required to consult with the DSPM repository for software reuse, where applicable. As programs design new and unique software and services, they are required to populate the DSPM repository with new information and make the service available for reuse, within Government Data Rights constraints.

4.5.3 Collaborating Communities

DoD has long recognized the value in fostering collaboration between Government, industry, and academia in open forums to address interoperability and common standards. To that end, a

number of integrated product teams, working groups, and other communities have formed, under the auspices and support of OUSD(AT&L), to address the interoperability challenge. These forums have enabled the Government to engage with industry at all levels, from grassroots to executive, and have enabled DoD personnel to aid in the systems and architecture design process, rather than simply being customers. These collaborating communities exist within a variety of national and international standards bodies, span the domains of unmanned systems (i.e., UAS, UGS, UMS), and address key cross-domain areas as well as domain-unique capabilities. DoD intends to continue to support this type of collaboration as it fosters the development of OAs. Current examples of these communities include the following:

- The OUSD(AT&L)-chartered UAS Task Force to coordinate critical DoD UAS issues and develop a path to enhance operations, enable interdependencies, facilitate interoperability, and streamline UAS acquisition. Within the UAS Task Force, the I-IPT has been chartered to promote UAS interoperability across the Services. The I-IPT establishes a central coordination forum for the Services' acquisition organizations and participating industry partners to share ideas that will allow the Department to build interoperability within the deployed UAS infrastructure, individual systems, and interfaces with appropriate manned weapons systems and C2 capabilities.
- Under the guidance of the Defense Science and Technology Advisory Group, the Autonomy Systems Community of Interest (CoI) closely examine the DoD's S&T investments in the enabling of autonomous systems. Specifically, this CoI identifies potential investments to advance and initiate critical enabling technology developments and strategically assesses the challenges, gaps, and opportunities to develop and advance autonomous systems.
- The National Geospatial-Intelligence Agency (NGA) is a member of the U.S. Intelligence Community and a Department of Defense (DoD) Combat Support Agency. NGA provides support to civilian and military leaders and contributes to the state of readiness of U.S. military forces by providing geospatial intelligence (GEOINT) imagery, imagery intelligence and geospatial data (e.g., mapping, charting and geodesy), and information to ensure the knowledge foundation for planning, decision and action. NGA also contributes to humanitarian efforts, such as tracking floods and disaster support, and to peacekeeping. NGA provides unmanned systems, topographical and terrestrial data, geodesy and geophysical data, imagery and precise position and target data for unmanned system mission planning and UAS flight operations. GEOINT support includes aeronautical and safety of navigation data, vertical obstruction, digital terrain elevation data and hydrographic data.
- NATO's Joint Capability Group on Unmanned Aerial Vehicles (JCGUAV) directs interoperability efforts in unmanned aviation. JCGUAV subsumed NATO's three Military Department UAS-related groups (PG-35, Air Group 7, and Task Group 2) in 2006. Its major accomplishments to date include STANAG 4586 for UAS message formats and data protocols, STANAG 4671 for UAV Airworthiness Standard, and STANAG 7085 for the CDL communication system, which has been mandated by OSD since 1991.
- NATO's Joint Capability Group Intelligence Surveillance and Reconnaissance (JCGISR) provides interoperability between NATO and Coalition ISR systems and includes

standards related to imagery formats and interfaces, data storage interfaces, motion imagery, electronic intelligence reporting, and imaging systems data links.

- Current UAS System Interoperability Profiles (USIPs), produced by the I-IPT, define the standard interface for payload products and the data link between a control station and air vehicle for line of sight (LOS) and beyond line of sight (BLOS) scenarios. Future USIPs will address other aspects of interoperability to include data encryption, additional data link technologies such as bandwidth efficient common data link (BE-CDL), and enhanced capabilities provided by future sensors.
- The Joint Architecture for Unmanned Systems (JAUS) began in 1995 as an effort by the Army's program office for UGVs in the Aviation and Missile Research, Development and Engineering Center (AMRDEC) at Redstone Arsenal to establish a common set of message formats and data protocols for UGVs. Deciding to convert JAUS to an international industry standard, the program office approached the Society of Automotives Engineers (SAE), a standards development organization (SDO) with robotics experience, which established the AS-4 Unmanned Systems Committee in August 2004. AS-4 has three subcommittees focused on requirements, capabilities, and interfaces and an experimental task group to test its recommended formats and protocols before formally implementing them. The migration to the SAE is complete, and the first set of SAE JAUS standards, focusing on the JAUS Service Interface Definition Language (JSIDL), core services, mobility services, manipulation services, and environmental sensing services, has been balloted and released. Although AS-4 is open to its members creating standards on other aspects of unmanned systems beyond message formats and data protocols for UGVs, much of this broader work is now being undertaken by other UAS-related SDOs. STANAG 4586 is unmanned aviation's counterpart to JAUS.
- The Navy's Program Executive Officer of Littoral and Mine Warfare (PEO(LMW)) formally adopted JAUS message formats and data protocols for use with its UUVs, USVs, and UGVs in 2005. Working through SAE AS-4, the Naval Undersea Warfare Center (NUWC) expanded JAUS to serve the UMS community. It found only 21% of UMS message formats to be directly compatible with the formats of JAUS, with the high percentage of new formats needed possibly due to the operation of UMS in three dimensions versus the two dimensions of UGVs, for which JAUS was developed. UUV variants of JAUS services are in active development and have been presented to the SAE AS-4 committees.
- Under direction from the OUSD(AT&L),[11] the UAS Task Force chartered the UAS Control Segment (UCS) Working Group, which is tasked to develop and demonstrate a common, open, and scalable UAS architecture supporting UAS Groups 2 to 5 (see Fig 1. DoD UAS for Groupings). The UCS Working Group comprises Government and industry representatives and operates using a technical society model where all participants are encouraged to contribute in any area of interest. This effort incorporates the best practices of current Army, Air Force, and Navy development efforts to include, but not limited to, the following:

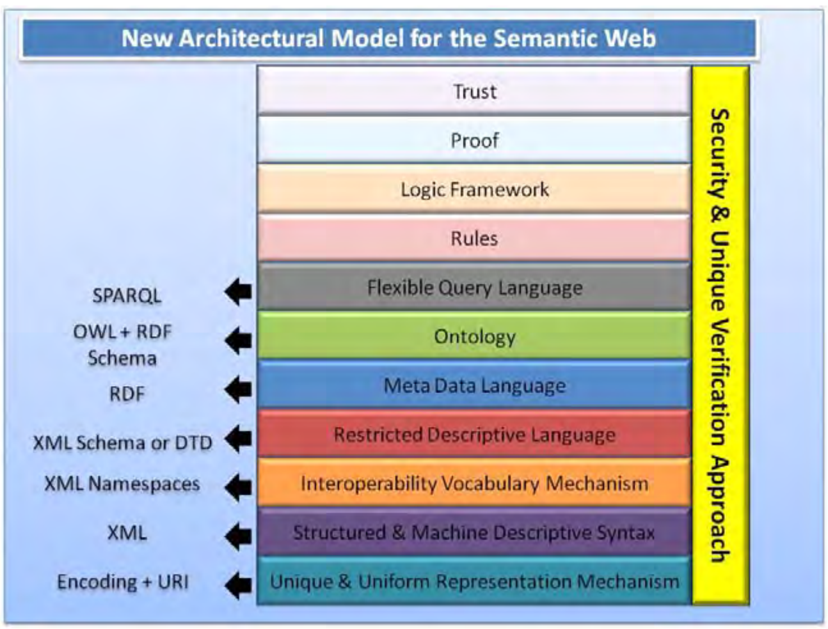
[11] OUSD(AT&L) Acquisition Decision Memorandum, 11 February 2009.

- Definition of a common functional architecture, interface standards, and business rules
- Use of open-source and Government-owned software as appropriate
- Competitive acquisition options
- Refinement of message sets to support all operational requirements of the systems previously defined

In addition to the definition of common capability descriptions, standards, data models, and architectures, DoD continues to promote the development of OA tools and to aid system acquisition and development in embracing the OA concepts. These efforts extend across the technology and unmanned vehicle spectrum, from software development kits, to complete architectures, addressing UGVs, UMVs, and UAVs, across all Services. Examples of such tools include:

1. The JAUS Tool Set (JTS) is a tool to help developers build JAUS-compliant software components without having to be intimately familiar with the details of JAUS. JTS allows an unmanned system designer to focus on behavior rather than messaging, protocol, and other considerations by providing a graphical user interface (GUI) service editor, validator, internal repository, C++ code generation, and hypertext markup language (HTML) document generation.

   The Navy and OSD have supported and promoted the use of the JTS and have had success incorporating it into development and acquisition efforts. Use of JTS on programs accrues benefits to a number of stakeholders in the acquisition chain and RDT&E community. These benefits include enabling a fair basis for competition among vendors so that true capabilities are evaluated; reducing vendor lock-in on unmanned systems; and enabling the development of a service repository for JAUS capabilities that have been developed and are available for reuse. JTS reduces the threshold for entry into developing JAUS-compliant systems, opens the market to small businesses, and drives competition and innovation focused on core technology. In addition, JTS provides an accepted, common validation capability, which is critical to ensure systems maintain compliance with JAUS.



2. The STANAG 4586 Compliance Toolkit (4586CT) is an integrated set of software tools that provides passive, interactive, and automated test capability. Its core function is to verify the structure and content of data link interface (DLI) messages against both STANAG 4586 and "private" messages as defined to support service-, mission-, or platform-specific requirements. This nonintrusive capability is provided either in real time or during post-run analysis. Additionally, 4586CT can be interoperable with other DLI-compatible systems in either manual mode (where an engineer monitors and injects DLI messages into the network) or automated mode (in which 4586CT interacts directly with other DLI systems according to user-defined scripts and procedures).

   These capabilities enable 4586CT to perform compliance testing at both the message level and the higher protocol session levels of unmanned systems relative to the STANAG 4586, and other more specific interoperability profiles. Complex DLI message dialogs can be monitored and system interaction sequencing verified as 4586CT follows user-defined test programs. Because 4586CT can function as a proxy for other unmanned system components, it is also used during system development and task-specific integration testing to provide insight into unmanned system interaction and performance. Multiple instances of 4586CT can also be utilized to perform rapid prototyping of interoperation protocols during profile design; as a result, 4586CT can be a useful tool during the development of interoperability standards themselves.

The T&E of interoperability continues to evolve with the growth of unmanned systems. The C2 of these systems presents unique test challenges as autonomous functionality expands to operating complex equipment over wireless links. The spectrum of test includes assessment of standards compliance, electromagnetic frequency testing, sensor standards, payload standards, systems interoperability, quantifiable task assessment, performance measurement, metrics development, congestion management, and performance baseline measures. The scope of operation includes operator, platform, communications grid, C2 teams, ground stations, sensor teams, and collaborating systems. While today's test represents a migration of the test challenge represented by proprietary data exchange and data formats towards service-oriented architecture exchange, it is also conceivable that the cognitive nature of unmanned systems algorithm development may actually accelerate the need for semantic knowledge exchange T&E.

The rapid acquisition of quickly evolving unmanned systems will require an unmanned systems T&E capability that evolves at a pace that exceeds this evolution. The T&E of unmanned systems interoperability requires investment in information architectures, methodology, test scenario synthesis, model-based T&E, and cross-UAS usage case repositories.

4.5.4 System Migration

Services working with OUSD(AT&L) are exploring the business case for adopting an OA approach for current and in-development systems. While various challenges still remain in the adoption of OA, the goal in the next 12 months is to identify migration pathways for all current programs of record (see Figure 9).

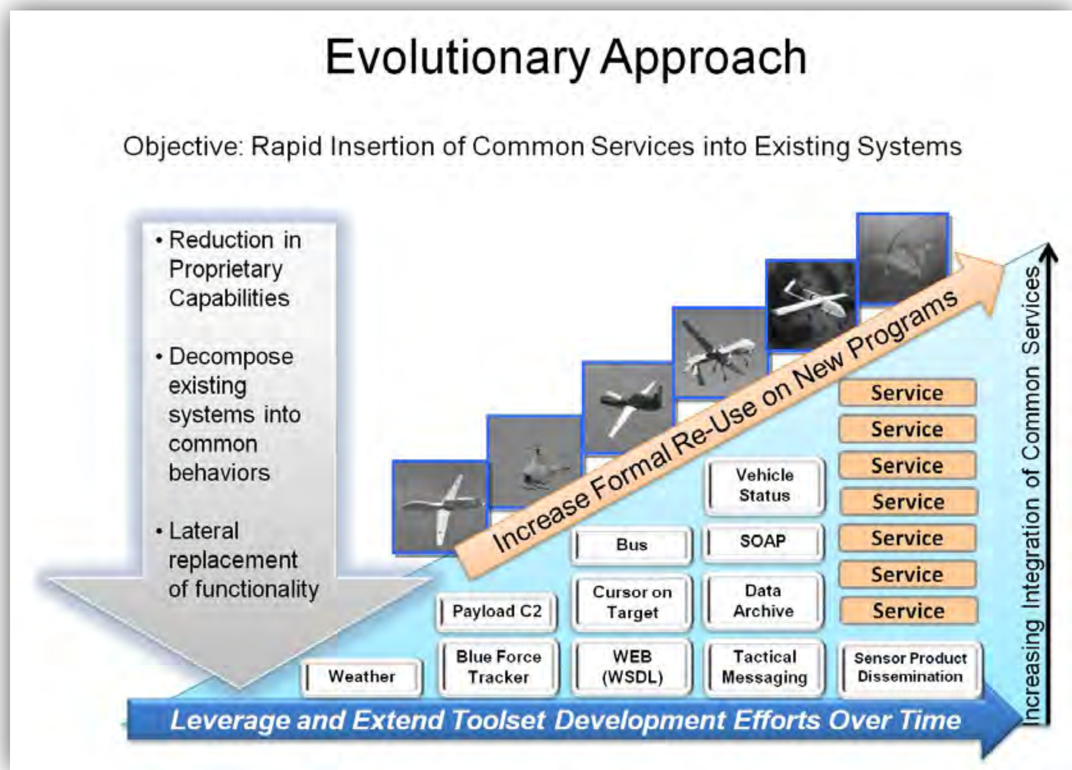


Figure 9. OA Migration Approach.

Quantifiable progress toward migration has already been achieved. The USAF Advanced Cockpit Block 50 (under development by General Atomics) has adopted UCS services and a common data bus. The July 2010 Block 50 implementation of takeoff, flight, payload C2, and landing utilized UCS-based software in a simulated flight environment demonstrated the architecture's utility. Additionally, Northrop Grumman has now agreed to tie its product lines into a common, open product line, with a joint mission-planning-mission-control system document signed by Northrop Grumman executives for synergy and collaboration between Broad Area Maritime Surveillance (BAMS) and Global Hawk unmanned systems. Advanced Explosive Ordnance Robotic System (AEODRS), utilizing an OA approach for hardware and software, is adopting SAE JAUS for messaging and is also developing interoperability profiles to ensure common system functionality descriptions, architectures, and data models. AEODRS is developing three classes of vehicles (dismounted operations, tactical operations, and base/infrastructure operations) with a common architecture and capability modules across the FoS. The AEODRS architecture defines the logical, mechanical, and electrical interfaces for the FoS. The AEODRS is entering Milestone B, and the development of increment 1 (dismounted operations) is now starting.

In addressing interoperability for ground systems, Robotic Systems Joint Project Office (RS-JPO) is utilizing SAE JAUS for messaging (with custom extensions as necessary) and primarily focusing on communications, payloads, power, architecture, and controller. Progress has already been made, with a modeling and simulation demonstration and an Input/Output (IO) Specification Build V1 planned for 2012.

4.6 Summary

We can no longer afford to acquire independent, proprietary unmanned systems that do not leverage interoperability. The lines in the battlespace are blurring, and the need to share information, sensors, payloads, and platforms is real. The fiscal battlespace is also blurring, and vendors must shift strategies to adhere to standards, drive toward OAs, reuse software, and develop robust repositories. The goal is to provide more capable unmanned systems to the warfighter on time, and interoperability will ultimately play a large role in this effort by enabling the composition of novel systems capabilities on a faster timescale. Figure 10 depicts an interoperability path for the future as industry and DoD strive to become more efficient.

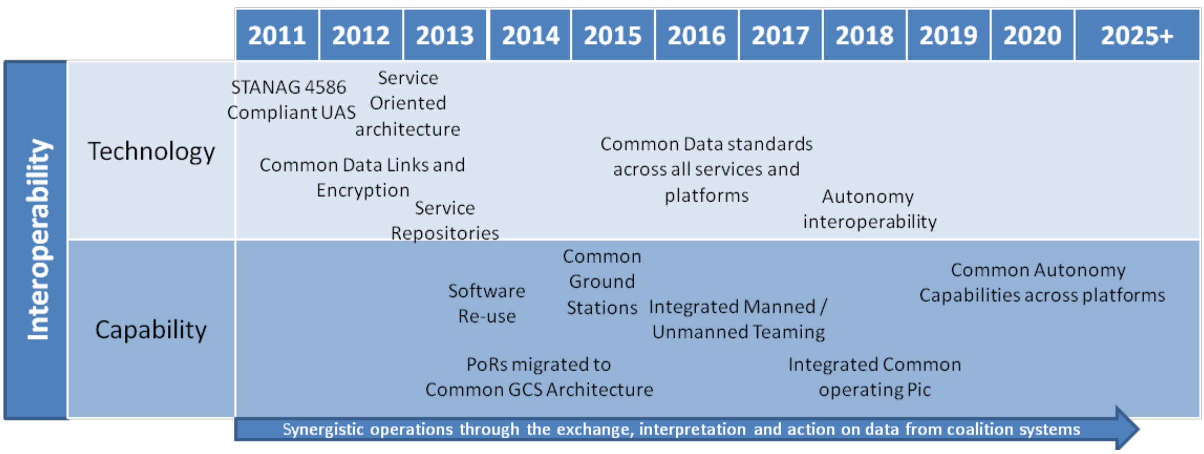


Figure 10. Interoperability Roadmap.

5 AUTONOMY

Dramatic progress in supporting technologies suggests that unprecedented levels of autonomy can be introduced into current and future unmanned systems. This advancement could presage dramatic changes in military capability and force composition comparable to the introduction of "net-centricity." DoD must understand and prepare to take maximum practical advantage of advances in this area.[12]

5.1 Functional Description

Automatic systems are fully preprogrammed and act repeatedly and independently of external influence or control. An automatic system can be described as self-steering or self-regulating and is able to follow an externally given path while compensating for small deviations caused by external disturbances. However, the automatic system is not able to define the path according to some given goal or to choose the goal dictating its path.

By contrast, autonomous systems are self-directed toward a goal in that they do not require outside control, but rather are governed by laws and strategies that direct their behavior. Initially, these control algorithms are created and tested by teams of human operators and software developers. However, if machine learning is utilized, autonomous systems can develop modified strategies for themselves by which they select their behavior. An autonomous system is self-directed by choosing the behavior it follows to reach a human-directed goal. Various levels of autonomy in any system guide how much and how often humans need to interact or intervene with the autonomous system, and these levels will be discussed shortly. In addition, autonomous systems may even optimize behavior in a goal-directed manner in unforeseen situations (i.e., in a given situation, the autonomous system finds the optimal solution).

The special feature of an autonomous system is its ability to be goal-directed in unpredictable situations. This ability is a significant improvement in capability compared to the capabilities of automatic systems. An autonomous system is able to make a decision based on a set of rules and/or limitations. It is able to determine what information is important in making a decision. It is capable of a higher level of performance compared to the performance of a system operating in a predetermined manner.[13]

5.2 Today's State

In 2010, the USAF released the results of a year-long study highlighting the need for increased autonomy in modern weapon systems, especially given the rapid introduction of UAS. This study, "Technology Horizons," identified the need for greater system autonomy as the "*single greatest theme*" for future USAF S&T investments. The study cited the potential for increased autonomy to improve effectiveness through reduced decision cycle time while also enabling manpower efficiencies and cost reductions.

[12] USD AT&L *Memo to Chairman, Defense Science Board, Subj Terms of Reference*, 29 March 2010.
[13] NATO Industrial Advisory Group, Study Group 75, Annex C - Autonomous Operations, 2004.

Autonomous capabilities have been enabled by advances in computer science (digital and analog), artificial intelligence, cognitive and behavioral sciences, machine training and learning, and communication technologies. In order to achieve operational acceptance and trust of these autonomous capabilities in the highly dynamic unmanned system environment, improvement is essential in advanced algorithms that provide robust decision-making capabilities (such as machine reasoning and intelligence); automated integration of highly disparate information; and the computational construct to handle data sets with imprecision, incompleteness, contradiction, and uncertainty.

In response to CCDR needs, the USAF has aggressively expanded UAS capabilities to a target of 65 combat air patrols (CAPs). According to the USAF, 1750 pilots from the Total Force (Active, Guard, and Reserve) are required to maintain these CAPs, which operate around the clock. This increasing manpower requirement is occurring at a time when constrained budgets are limiting growth in Service manpower authorizations. This challenge is not limited to the USAF, but is facing all the military Services. Today's unmanned systems require significant human interaction to operate. As these systems continue to demonstrate their military utility, exploit greater quantities of intelligence, and are fielded in greater numbers, the demand for manpower will continue to grow. The appropriate application of autonomy is a key element in reducing this burden.

> Our Program Managers should be scrutinizing every element of program cost, assessing whether each element can be reduced relative to the year before, challenging learning curves, dissecting overheads and indirect costs, and targeting cost reduction with profit incentive—in short, executing to what the program should cost.
>
> *–Under Secretary of Defense Memorandum for Acquisition Professionals, Better Buying Power, September 2010*

5.3 Problem Statement

The increased manpower to operate unmanned systems is adding stress to the overall workload of the armed forces. This stress highlights the need to transition to a more autonomous, modern system of warfare. The USAF Chief of Staff General Norton Schwartz emphasized the need for more automation in the following statement:[14]

> [The trend] cannot continue indefinitely. There is a place for automation here that reduces the manpower requirement, both to operate and to process the backend data stream.
>
> *– Gen Norton Schwartz, Air Force Chief of Staff*

[14] Fontaine, Scott, "Schwartz outlines possible future changes," *Air Force Times*, 30 August 2010.

For unmanned systems to fully realize their potential, they must be able to achieve a highly autonomous state of behavior and be able to interact with their surroundings. This advancement will require an ability to understand and adapt to their environment, and an ability to collaborate with other autonomous systems, along with the development of new verification and validation (V&V) techniques to prove the new technology does what it should. Each of these topics is discussed in more detail below. Advances in autonomy at the system level must proceed with awareness of potential disadvantages and vigilance for unintended consequences, which may include diminished command over parts of the forces structure. Every operation includes rules of engagement, air tasking order (ATO)/special instructions (SPINS), and options of dynamic changes of command direction; and intent must not be traded off. The ability to respond to the unexpected cannot be diminished. For example, dealing with volcanic ash in the atmosphere cannot be reliably predicted at the beginning of an eruption. The ability to respond and avoid affected airspace is an example of a condition that may be difficult for autonomy to address. Implementing autonomy can lead to a loss of human attention to vital oversight in matters having potentially dangerous or lethal consequences. Caution must be used at the system-of-systems level, and constraints applied in some operations in order to allow autonomy in others. Finally, surrendering decision trust to a software-based and self-learning design outside the context of specific operations is a matter of high rigor, and must be examined in the context of organizational-unit and theater CONOPS.

5.4 Way Ahead

Significant advances have been made in autonomy, but many challenges still exist. For relatively static environments and undemanding missions and objectives, rule-based autonomous systems can be highly effective. However, most DoD environments and mission tasks dictate that unmanned systems operate in complex and uncertain environments as well as possess the ability to interact and collaborate with human operators and human teammates. Additionally, autonomous systems need the capability to interact and work together with other autonomous systems, to adapt to and learn from changes in the environment and missions, and to do so safely and reliably. One goal of automation is to leap forward in capabilities using human augmentation. Automated assistance of whatever kind does not simply enhance our ability to perform the task: it changes the nature of the task itself.[15]

5.4.1 Transcending to Higher Levels of Autonomy

Autonomy reduces the human workload required to operate systems, enables the optimization of the human role in the system, and allows human decision making to focus on points where it is most needed. These benefits can further result in manpower efficiencies and cost savings as well as greater speed in decision making. Autonomy can also enable operations beyond the reach of external control or where such control is extremely limited (such as in caves, under water, or in areas with enemy jamming or degraded communications). Advances in autonomy will further increase operational capability, manpower efficiencies, and cost savings.

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[15] Norman, D. A., "How might people interact with agents?" *Software Agents*, J. M. Bradshaw, Ed. Cambridge, MA: The AAAI Press/The MIT Press, 1997, pp. 49–55.

> … the ability to understand and control future costs from a program's inception is critical to achieving affordability requirements.
>
> *–Under Secretary of Defense Memorandum for Acquisition Professionals, Better Buying Power, September 2010*

While reduced reliance on human operators and analysts is the goal of autonomy, one of the major challenges is how to maintain and facilitate interactions with the operator and other human agents. An alternative statement of the goal of autonomy is to allow the human operator to "work the mission" rather than "work the system." In other words, autonomy must be developed to support natural modes of interaction with the operator. These decision-making systems must be cognitively compatible with humans in order to share information states and to allow the operator and the autonomous system to interact efficiently and effectively. The level of autonomy should dynamically adjust based on workload and the perceived intent of the operator. Common terms used for this concept are *sliding autonomy* or *flexible autonomy*. The goal is not about designing a better interface, but rather about designing the entire autonomous system to support the role of the warfighter and ensure trust in the autonomy algorithms and the system itself. Table 3 contains the most commonly referenced description of the levels of autonomy that takes into account the interaction between human control and the machine motions.

Table 3. Four Levels of Autonomy

Level	Name	Description
1	Human Operated	A human operator makes all decisions. The system has no autonomous control of its environment although it may have information-only responses to sensed data.
2	Human Delegated	The vehicle can perform many functions independently of human control when delegated to do so. This level encompasses automatic controls, engine controls, and other low-level automation that must be activated or deactivated by human input and must act in mutual exclusion of human operation.
3	Human Supervised	The system can perform a wide variety of activities when given top-level permissions or direction by a human. Both the human and the system can initiate behaviors based on sensed data, but the system can do so only if within the scope of its currently directed tasks.
4	Fully Autonomous	The system receives goals from humans and translates them into tasks to be performed without human interaction. A human could still enter the loop in an emergency or change the goals, although in practice there may be significant time delays before human intervention occurs.

> The single greatest theme to emerge from "Technology Horizons" is the need, opportunity, and potential to dramatically advance technologies that can allow the Air Force to gain the capability increases, manpower efficiencies, and cost reductions available through far greater use of autonomous systems in essentially all aspects of Air Force operations. Increased use of autonomy — not only in the number of systems and processes to which autonomous control and reasoning can be applied but especially in the degree of autonomy that is reflected in these — can provide the Air Force with potentially enormous increases in its capabilities, and if implemented correctly can do so in ways that enable manpower efficiencies and cost reductions.
>
> *– USAF Report on Technology Horizons: A Vision for Air Force Science and Technology During 2010-2030, 15 May 2010*

5.4.2 Ability to Understand and Adapt to the Environment

To operate in complex and uncertain environments, the autonomous system must be able to sense and understand the environment. This capability implies that the autonomous system must be able to create a model of its surrounding world by conducting multisensor data fusion (MDF) and converting these data into meaningful information that supports a variety of decision-making processes. The perception system must be able to perceive and infer the state of the environment from limited information and be able to assess the intent of other agents in the environment. This understanding is needed to provide future autonomous systems with the flexibility and adaptability for planning and executing missions in a complex, dynamic world.

Although such capabilities are not currently available, recent advancements in computational intelligence (especially neuro-fuzzy systems), neuroscience, and cognition science may lead to the implementation of some of the most critical functionalities of heterogeneous, sensor net-based MDF systems. The following developments will help advance these types of processing capabilities:

1. **Reconfigurability of sensor weighting:** When a heterogeneous sensor net is used for an MDF system, each sensor has a different weight for different applications. As an example, regardless of whether a dissimilar MDF methodology is used to identify an object, an image sensor has much higher weight than radar. On the other hand, when an MDF methodology is used to measure a distance from the sensor to an object, a rangefinder or radar has a much higher weight than an image sensor.
2. **Adaptability of malfunctioning sensors and/or misleading data:** Even if an MDF methodology is used to identify an object, an image sensor cannot perform if it is faced to the sun. Data from the image sensors will either be saturated or need to be calibrated. Additionally, the image sensor data needs to be continuous calibrated if the weather is cloudy and changing because the measured data will be different based on shadows and shading. Therefore, the environment of a heterogeneous sensor net is a key parameter to be considered for design and implementation of an MDF system.

3. **Intelligent and adaptive heterogeneous data association:** Heterogeneous, sensor net-based MDF systems must process different data simultaneously, such as one-dimensional radar signals, two-dimensional imaging sensor data, etc. As the combination of heterogeneous sensors change, the data combination is changed. Therefore, adaptive data association must be performed before conducting MDF and data input to the decision-making module.
4. **Scalability and resource optimization of self-reconfigurable fusion clusters:** The limiting factor of an MDF system is the scalability of self-reconfiguring the fusion cluster to adapt to a changing battlefield and/or the malfunction of one or more sensors. As the number of sensors used for a sensor net increases, the combinatorial number of reconfigurations exponentially increases. To manage such complexity, the MDF system will require a highly intelligent, fully autonomous, and extremely versatile reconfigurable algorithm, including sensor resource management and optimization. Great progress has been made in sensor management algorithms and cross-cued sensor systems, but true optimization is an elusive goal that is currently unavailable. Such capability can be obtained only from intelligent computing technology, which is currently in its infancy.

While robustness in adaptability to environmental change is necessary, the future need is to be able to adapt and learn from the operational environment because every possible contingency cannot be programmed *a priori*. This adaptation must happen fast enough to provide benefits within the adversary's decision loop, and the autonomy should be constructed so that these lessons can be shared with other autonomous systems that have not yet encountered that situation. Yet even in a hostile, dynamic, unstructured, and uncertain environment, this learning must not adversely affect safety, reliability, or the ability to collaborate with the operator or other autonomous systems. The flexibility required of autonomous systems in dynamic, unstructured environments complicates the predictability needed for U.S. commanders to "trust" the autonomy.

"Trust" will be established through robust operational T&E along with safeties and safeguards to ensure appropriate behavior. Complex autonomous systems must be subject to rigorous "red team" analysis in order to evaluate the full range of behaviors that might emerge in environments that simulate real-world conditions. Safeties and safeguards are also required to mitigate the consequences of failures. Because artificial systems lack the human ability to step outside a problem and independently reevaluate a novel situation based on commander's intent, algorithms that are extremely proficient at finding optimal solutions for specific problems may fail, and fail badly, when faced with situations other than the ones for which they were programmed. Robust safeties and control measures will be required for commanders to trust that autonomous systems will not behave in a manner other than what is intended on the battlefield.

5.4.3 Enabling Greater Autonomy in TPED Processes

In addition to C2 processes, traditional TPED processes offer huge opportunities for reducing the degree of human involvement. Near-term developments could introduce a greater degree of automation, ultimately evolving to more autonomous systems. Current TPED processes are manpower intensive. In today's combat environment, most full-motion video (FMV) and still imagery is monitored and used in real time, but then stored without being fully analyzed to exploit all information about the enemy. This challenge is not unique to the unmanned

environment, but it has been exacerbated by the large numbers of ISR-capable, long-endurance unmanned systems being fielded. These systems are collecting great quantities of information and overwhelming current TPED processes. Near-term steps might include implementation of change detection and automatic target recognition software to enable automated cueing that identifies and calls attention to potential threats. Applications of face recognition software could enable high-fidelity FMV to identify individuals of interest. Increased automation in communications intelligence sensors has the potential to identify key words and even specific voices to rapidly alert operators to targets of interest. Ultimately, automated cross-cueing of different sensor types in a networked environment could enable greater autonomy in tasking systems and their sensors to identify and track threats more rapidly.

Increased processing power and information storage capacities also have the potential to change how unmanned systems operate. For example, many current UAS transmit ISR data that is processed and exploited in ground stations. If more processing and exploitation processes can be accomplished onboard a UAS (like the automatic target recognition or communications intelligence examples discussed above), the system can disseminate actionable intelligence for immediate use and reduce bandwidth requirements. FMV ISR, for example, uses roughly an order of magnitude more bandwidth than the C2 data for a UA. By accomplishing more of the TPED process onboard the unmanned system, the link bandwidth can then be focused on transmitting only what's needed, and the overall bandwidth requirements can be reduced.

> Today an analyst sits there and stares at Death TV for hours on end trying to find the single target or see something move or see something do something that makes it a valid target. It is just a waste of manpower. It is inefficient!
>
> *– Gen James Cartwright, Vice Chairman of the Joint Chiefs of Staff, during remarks to the U.S. Geospatial Intelligence Foundation on 4 Nov 2010*

5.4.4 Ability to Collaborate with Other Autonomous Systems

In addition to understanding the environment, unmanned systems must also possess the ability to collaborate through the sharing of information and deconfliction of tasking. Collaborative autonomy is an extension of autonomy that enables a team of unmanned systems to coordinate their activities to achieve common goals without human oversight. This trend in autonomy will continue to reduce the human role in the system. Autonomously coordinated unmanned systems may be capable of faster, more synchronized fire and maneuver than would be possible with remotely controlled assets. This trend will lead to a shift toward strategic decision making for a team of vehicles and away from direct control of any single vehicle.

The ability to collaborate is one of the keys to reducing force structure requirements. The collaborative autonomy that is developed must be scalable to both larger numbers of heterogeneous systems as well as increased mission and environment complexity. Collaborative autonomy must be able to adapt to the air, ground, and maritime traffic environment and to changes in team members, operators, and the operational environment.

5.4.5 Development of New Approaches to Verification and Validation (V&V)

To ensure the safety and reliability of autonomous systems and to fully realize the benefits of these systems, new approaches to V&V are required. V&V is the process of checking that a product, service, or system meets specifications and that it fulfills its intended purpose. These components are critical in a quality management system such as ISO 9000. Today's V&V processes will be severely stressed due to the growth in the amount and complexity of software to be evaluated. They utilize existing industry standards for software certification that are in place for manned systems (e.g., DO-178B). Without new V&V processes, such as the use of trust audit trails for autonomy, the result will be either extreme cost growth or limitations on fielded capabilities.

Efforts leading to advancements in computational intelligence as well as the appropriate V&V processes are essential. Enhanced V&V technologies would provide both near-term cost reduction and enhanced capabilities for current autonomous systems and would enable otherwise cost-prohibitive capabilities in the future. New autonomous system test and analysis capabilities are also required to assess intelligent single-vehicle and group behaviors. These technological enhancements and policy actions would lead to more effective development, testing, and operations of current and future autonomous systems.

5.4.6 Policy Guidelines to Ensure Safe Operation

Additional measures, beyond V&V, will be required to ensure safe operation of autonomous systems. No V&V process can guarantee 100% error-free operation of complex systems. As software complexity increases, predicting the precise behavior of autonomous systems in real-world environments will be increasingly difficult. Policy guidelines are necessary in order to ensure that if failures or malfunctions occur, or if an unmanned system encounters an unanticipated situation, the system continues to operate appropriately.

Policy guidelines will especially be necessary for autonomous systems that involve the application of force. Current armed, unmanned systems deploy lethal force only in a fully human-operated context (level 1) for engagement decisions. For these systems, the decisions both to employ force and to choose which specific target to engage are made by a human. The United States does operate defensive systems for manned ships and installations that have human-supervised autonomous modes (level 3), and has operated these systems for decades. For the foreseeable future, decisions over the use of force and the choice of which individual targets to engage with lethal force will be retained under human control in unmanned systems.

5.5 Summary

Technological advances in autonomy are critical as the need to field greater numbers of unmanned systems stresses the limited number of available operators. Challenges in the area of

autonomy address not only functionality, but also transparency to the operator, safety, and reliability. Figure 11 provides a vision into the future of the autonomy advances that are required to maintain an affordable force structure and confidently operate unmanned systems in an increasingly complex environment. Initially, autonomy will improve the safe operations of unmanned systems within the increasingly complex environment of military operations as well as reduce operator workload associated with mundane and noncritical processes. Ultimately, autonomy will increase warfighter effectiveness by enhancing unmanned systems capabilities and expanding their capacity to effect results in the battlespace.

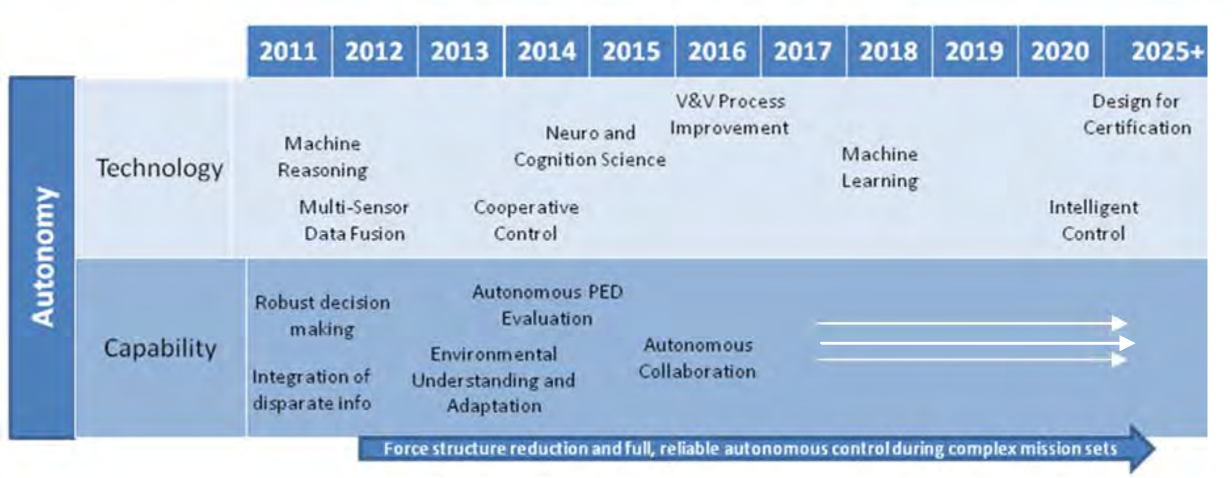

Figure 11. Autonomy Roadmap.

6 AIRSPACE INTEGRATION (AI)

6.1 Functional Description

Over the past several years, UAS have become a transformational force multiplier for DoD. The numbers and roles of UAS have expanded dramatically to meet mission demands, and operational commanders have come to rely upon robust and persistent ISR support from unmanned platforms executing their core missions against hostile forces. DoD UAS require routine NAS access in order to execute operational, training, and support missions and to support broader military and civil demands. UA will not achieve their full potential military utility to do what manned aircraft do unless they can go where manned aircraft go with the same freedom of navigation, responsiveness, and flexibility. Military aviation is a major contributor to the virtue of maneuver for our forces in warfare.

While the force structure continues to grow, the ability to integrate UAS into the NAS has not kept pace. Current access for UAS is greatly limited primarily due to FAA regulatory compliance issues that govern UAS operations in the NAS. DoD UAS operations conducted outside of restricted, warning, and prohibited areas are authorized only under a (temporary) COA from the FAA. Similar issues need to be resolved for access to international and foreign national airspace.

The *DoD UAS Airspace Integration Plan, March, 2011* provides a more comprehensive discussion on the topic of AI. In this plan, DoD provides an incremental approach strategy to provide DoD UAS access to a given operations profile that leads to a full dynamic operations solution. This methodology recognizes that DoD requires access to differing classes and types of airspace as soon as possible and that routine dynamic operations will likely take several years to implement. Figure 12 depicts the six access profiles.

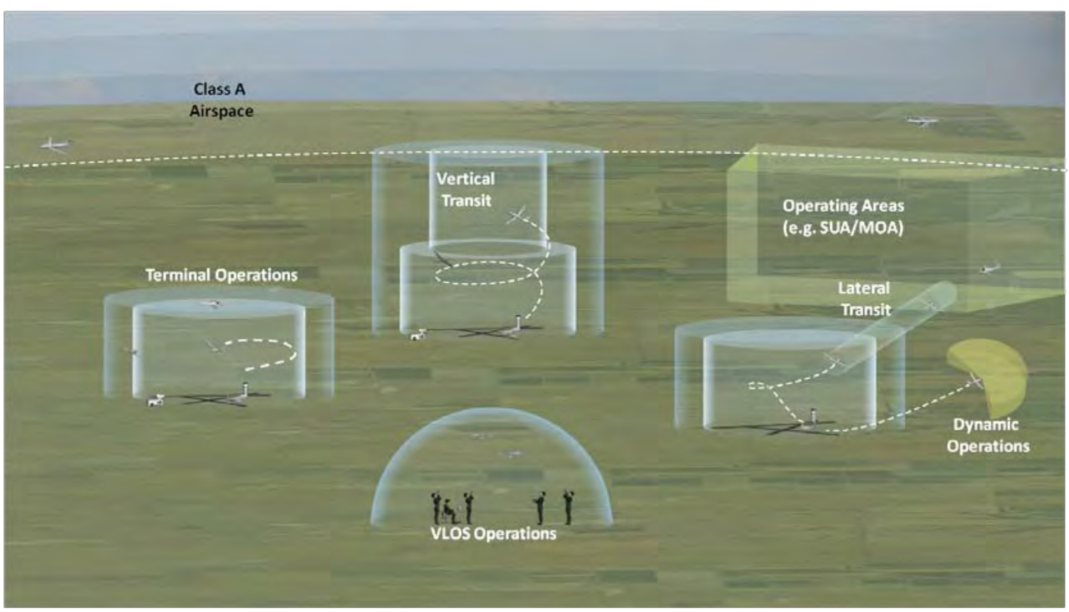

Figure 12. Operational View.

6.1.1 Vision

NAS Access Requirements

- Aircraft must be Airworthy
- Must be operated by a Qualified Pilot / Operator
- Compliant with Operating Rules, Standards, and Procedures

DoD's vision is to ensure UAS have routine access to the appropriate airspace required to meet mission needs. For military operations, UAS will operate with manned aircraft using CONOPS that make manned or unmanned aircraft distinctions transparent to air traffic services (ATS) authorities and airspace regulators. Having robust UAS AI capabilities for all classes of U.S. airspace is fundamental to flexible worldwide UAS deployment.

> … it is vital for the Department of Defense and the Federal Aviation Administration to collaborate closely to achieve progress in gaining access for unmanned aerial systems to the National Airspace System to support military requirements.
>
> *– 110th Congress, NDAA for FY09, Sect 1039*

6.1.2 Precepts

Airspace Integration Precepts

- Apply Our World-leading Aviation Expertise to UAS
- Conform Where Possible, Create Where Needed
- Leverage DOD Authorities and Equities
- Engage as One

The *2010 DoD Airspace Integration Plan* outlines DoD's approach, which is summarized by four overarching precepts (see right). The U.S. military will use its vast experience to develop the safest, most capable UAS fleet possible. We will strive for maximum compliance with existing regulatory guidance and inform regulatory processes when changes are needed. DoD will fully leverage statutory authorities to design, test, and ultimately certify its UAS in compliance with applicable standards, regulations, and orders. The regulatory and policy changes may be broad in scope to affect multiple Military Departments and Combatant Commands (CCDRs); therefore, UAS AI activities should make every effort to be coordinated prior to engaging with FAA or other external agencies.

6.2 Today's State

In order for any military aircraft — manned or unmanned — to fly routinely in domestic and international airspace, three foundational requirements must be met. These three requirements are essential and form the foundation for UAS AI. Title 10 of the United States Code (USC) is the legal underpinning for the roles, missions, and organization of DoD and provides authority for the military departments to organize, train, and equip U.S. forces to fulfill the core duties for national defense. Consistent with this statutory authority and longstanding practice and reinforced by interagency agreements, DoD is responsible for establishing airworthiness and

pilot training/qualification requirements for the military and ensuring rigorous military standards are satisfied.[16] The third and most complex requirement, regulatory compliance, encompasses both internal military department regulations and external FAA and International Civil Aviation Organization (ICAO) flight regulations.

DoD Aircraft and Pilots/Operators Are Certified By DoD

6.2.1 Airworthiness

Airworthiness is a basic requirement for any aircraft system, manned or unmanned, to enter the NAS. The primary guidance for DoD airworthiness certification is found in MIL-HDBK-516B, *Airworthiness Certification Criteria.* This document defines airworthiness as "*the ability of an aircraft system/vehicle to safely attain, sustain and terminate flight in accordance with an approved usage and limitation.*"[17] Airworthiness certification ensures that DoD aircraft systems are designed, manufactured, and maintained to enable safe flight. Certification criteria, standards, and methods of compliance establish a minimum set of design and performance requirements for safely flying a given category and class of aircraft. The DoD is expanding current military airworthiness guidance to include criteria that address those component and system attributes that are unique to UA. UAS-unique standards derived from NATO STANAGs (e.g., 4671[18], 4705, and 4703) will be reviewed and incorporated as appropriate.

6.2.2 Pilot/Operator Qualification

The DoD determines where and how it will operate its aircraft, and each Military Department creates the qualification training programs necessary to safely accomplish the missions of that aircraft or weapon system. The standards to train and qualify pilots/operators of UAS will remain under the authority of the Military Departments and appropriate CCDRs. UAS pilot/operator training requires a different skill set from the set needed for flying manned aircraft due to differences such as the means of takeoff, cruising, and landing by visual remote, aided visual, or fully autonomous methods. Therefore, the Military Departments and CCDRs must apply the minimum training standards outlined in CJCSI 3255.01 to their respective training programs to ensure the requisite knowledge, skills, and abilities are addressed appropriately.

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[16] Title 10 provisions relating to service authority to organize, train, and equip include 10 U.S.C. Sec. 8062 (Air Force), 10 U.S.C. Sec. 3062 (Army), 10 U.S.C. Sec. 5062 (Navy), and 10 U.S.C. Sec. 5063 (Marine Corps). Multiple service instructions address airworthiness standards, e.g., Air Force Instruction 62-601, dated 11 June 2010.

[17] MIL-HDBK-516B with change 1, *Airworthiness Certification Criteria*, 29 February 2008.

[18] NATO STANAG 4671, Unmanned Aerial Vehicle Systems Air Worthiness Requirements (USAR).

6.2.3 Regulatory Compliance

The Military Departments have a robust process for establishing manned aircraft flight standards and procedures. However, the current ambiguity and lack of definition in national and international regulatory guidelines and standards for UAS make it difficult to know, with consistency or certainty, whether UAS can comply. In fact, some current UAS may already be operating at appropriate levels of safety; however, until the necessary UAS-specific standards, regulations, and agreed-upon compliance methodologies are defined, establishing regulatory compliance for more routine operations is difficult. In the meantime, UAS operations within the NAS are treated as exceptions through the COA process.

While many requirements can be met through the use of existing manned aircraft, many missions are more efficiently and safely accomplished by using unmanned platforms. Technology advancements may be able to help resolve regulatory compliance issues for UA (particularly Title 14 of the U.S. Code of Federal Regulations (14 CFR) 91.113 containing the see and avoid provision); however, the level and complexity of technology required to resolve today's regulatory compliance issues will negatively affect system affordability.

6.3 Problem Statement

The number of UAS in the DoD inventory is growing rapidly. The increase in numbers, as well as the expanding roles of UAS, has created a strong demand for access to national and international airspace and has quickly exceeded the current airspace available for military operations.

6.4 Way Ahead

6.4.1 Methodology

DoD's UAS NAS access methodology includes the array of UAS platform capabilities, required airspace, technology improvement, and implementation activities/products required to attain routine operations within the NAS. This methodology uses an incremental approach to provide DoD UAS access to a given operations profile that leads to a full dynamic operations solution (see Figure 13). This methodology recognizes that DoD requires access to differing classes and types of airspace as soon as possible and that routine dynamic operations will likely take several years to implement.

The profiles, as outlined in an operational view (Figure 12) and DoD's AI Plan, may be used individually to access specific local airspace or integrated together to satisfy additional airspace requirements. Visual LOS operations establish a means to conduct UAS operations in Visual Flight Rules conditions. The terminal area profile is intended to facilitate UAS operations in a confined volume of airspace, such as Class D airspace or near restricted airspace. UAS operating areas, such as special use airspace (e.g., restricted area, or military operations area (MOA)), can be accessed either by flying through a lateral corridor (through Class E) or by vertically ascending to Class A airspace and flying across. While operating areas are limited to restricted or warning areas, MOAs are desirable because they offer a wide variety of airspace spanning 43 states to provide a robust, nationwide UAS training capability without the creation of new airspace.

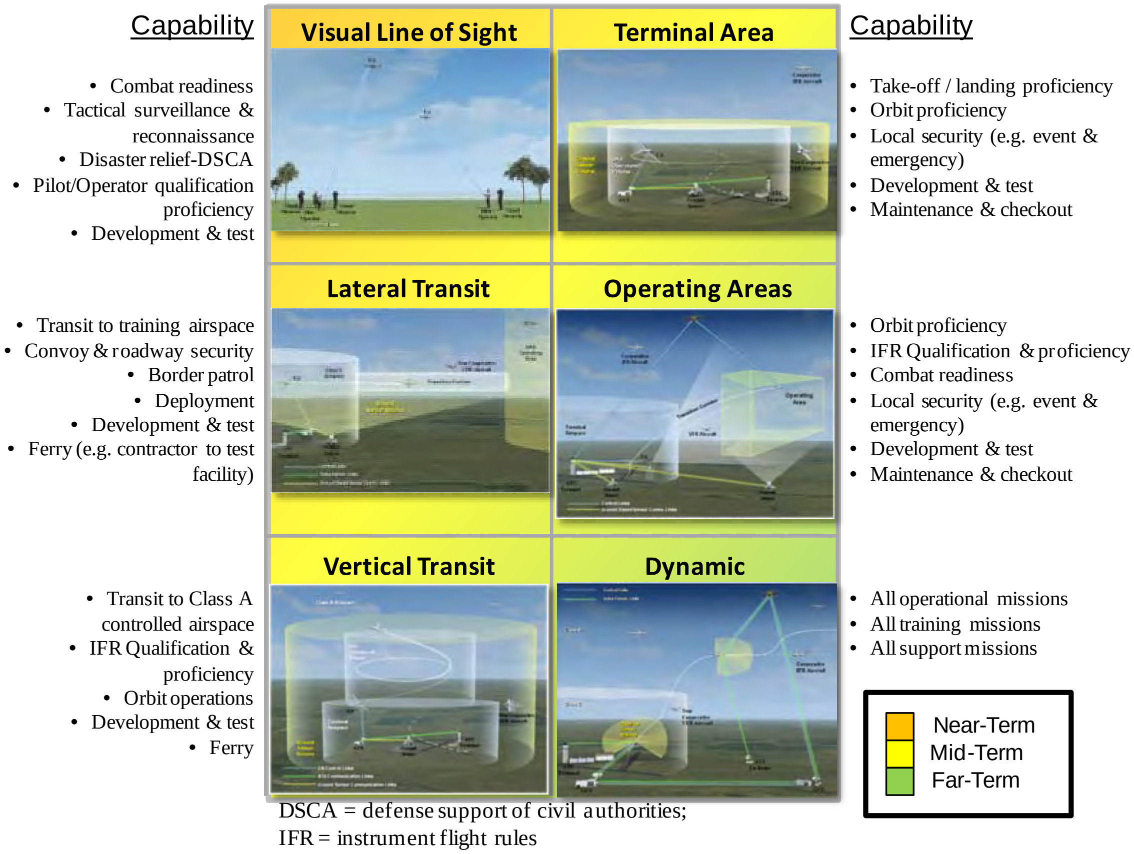


Figure 13. Incremental Approach to Regulatory Compliance.

Plans and programs to enable UAS operations within a profile will be evaluated for joint applicability and NAS access utility. For example, because most of the required near-term airspace for DoD UAS will be in Class D, E, and G, DoD intends to focus much of its near-term resources on addressing this major need.

6.4.2 Policy

Policy agreements can maintain the safety of the NAS while also allowing certain requirements to be fulfilled. In 2007, DoD and FAA signed a Memorandum of Agreement (MoA) allowing limited UAS operations for small UAS below 1200 ft above ground level (AGL) and UAS within DoD-controlled, non-joint-use Class D airspace. The 2007 MoA will be updated periodically, as needed, to allow DoD to incrementally increase access to the NAS. For example, the small UAS special federal aviation regulation is expected to be complete in 2013, but DoD can immediately leverage this work by seeking to incorporate many of the recommendations into an updated DoD-FAA MoA.

The Policy Board on Federal Aviation (PBFA) serves as the DoD liaison with the FAA on federal air traffic control and airspace management. The board provides policy and planning guidance to ensure the Military Departments have sufficient airspace to fulfill requirements. With support from OSD and the Military Departments, the board is working with FAA to update the 2007 MoA.

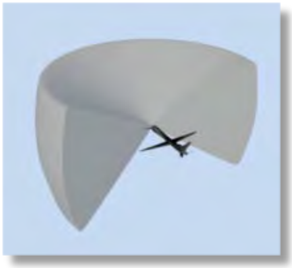
Where broader issues involve other agencies, the DoD participates in the UAS Executive Committee (ExCom). The ExCom acts as a focal point for senior leaders from FAA, DoD, DHS, and National Aeronautics and Space Administration (NASA) to meet periodically to resolve any policy and procedural disputes and to identify solutions to the integration of UAS into the NAS. The ExCom has established a working group to address COA issues, published a plan to Congress in October 2010, and continues to address specific issues such as collecting and sharing UAS safety data.

6.4.3 Technology

Current UAS are built to different specifications for different purposes; therefore, showing individually that each system is safe for flight in the NAS can be complicated, time consuming, and costly. Routine access cannot happen until DoD and FAA agree to an acceptable level of safety for UAS, and the appropriate standards are developed to meet that threshold. With developed standards, UA will be operationally treated as manned systems, and such treatment will improve interoperability with other systems, cost savings, and development transparency.

Until those necessary UAS-specific standards are established, requirements will be dependent on the individual system and intended flight environment (access profiles). Each system’s mission requirements will drive the selection of sense and avoid (SAA) solutions and process for implementation. Ground-based sense and avoid (GBSAA) can provide an initial means to maintain aircraft separation requirements for multiple profiles, while improvements to sensor and automation technology will continue to improve an airborne SAA (ABSAA) solution.

GBSAA efforts are focused on developing methods to provide aircraft separation within a prescribed volume of airspace using a ground-based system that includes sensors, displays, communications, and software. GBSAA solutions will incrementally relieve restrictions on existing COAs and facilitate UAS training and operations in the NAS. This effort is establishing requirements, gathering data, performing modeling and simulation, testing and verifying collected data, and obtaining airworthiness approvals, as appropriate. GBSAA can particularly benefit smaller UAS where other SAA solutions are cost prohibitive.



ABSAA efforts are focused on developing onboard capability to perform both self-separation and collision avoidance that ensure an appropriate level of safety. Current programs have phased validation schedules for due regard, en-route/Class A, and divert/ Class E/G operations as technology innovation and integration allow. GBSAA and ABSAA may be applied as a single or combined solution to some access profiles to maximize safety and/or reduce operational costs.

6.4.4 CONOPS Development

The DoD is developing an AI CONOPS to provide a framework for common UAS practices, procedures, and flight standards in NAS and international airspace. It is intended to standardize UAS access methodologies and procedures, implement appropriate methods for compliance with see-and-avoid requirements, and inform development of an UAS AI Initial Capabilities Document (ICD). It will establish a standard suite of lost-link, lost-communications, and lost-SAA procedures for DoD UAS in all phases of flight. These procedures will help define methods for notification and the appropriate action to either regain link or recover/divert the UA. The CONOPS also provides the operational and procedural construct to employ the access profiles at bases across the United States and to inform the process of basing UAS in locations outside the continental United States (OCONUS).

6.4.5 Requirements Development

The CONOPS, along with the Military Departments' individual location airspace requirements, will feed development of an UAS AI ICD. The UAS AI ICD is intended to identify the financial requirements for UAS integration into the NAS across the United States and OCONUS. As the initial SAA technologies mature through development and validation, they can be applied to the appropriate profiles and documented in the UAS AI ICD. This effort will allow the Military Departments to accurately estimate the costs to operate UAS at any given individual location as needed.

> … limited access to airspace is having a negative impact on the unmanned aviation community and many regions of the U.S. that are ready to support UAS industry growth.… over the next 15 years more than 23,000 UAS jobs could be created in the U.S. as the result of UAS integration into the NAS.
>
> – *Aerospace Industries Association. (2010). Total Employment: Annual Calendar Years 1990-2009. Available at AIA website: http://www.aia-aerospace.org/assets/stat12.pdf*

6.4.6 Timing of Activities

The DoD is focusing on near-term, mid-term, and far-term activities. This timing allows for immediate improvements in NAS access, while working toward viable long-term solutions.

- Near-term activities address small UAS, DoD-controlled airspace, and operations under COAs**.** Priority is given to initiatives that reduce COA requirements and streamline the FAA approval process. DoD believes significant near-term improvement in UAS NAS access is achievable through COA, policy, and procedural initiatives.
- Mid-term activities address local airfield and transit operations. Where policy and procedures fall short of achieving the long-term objective of routine access, a significant investment in standards and technology development is necessary. Priority is given to developing validated AI requirements and associated standards and to establishing an SAA capability that will provide NAS access through special rules and policy, new procedures, and use of ground-based sensor technology.
- Far-term activities address most UAS missions in any operating location and airspace to include FAA's Next Generation Air Traffic Control System (NextGen). The end state is routine NAS access comparable to manned aircraft for all DoD UAS.

6.5 Summary

DoD UAS have become a critical component of military operations. Many DoD UAS now require rapidly expanded access to the NAS and international civil airspace to support operations, training, testing, and broader governmental functions.

In order for military aircraft to fly routinely in domestic and international airspace, the aircraft must be certified as airworthy, operated by a qualified pilot/operator in the appropriate class(es) of airspace, and comply with applicable regulatory guidance. DoD exercises sole certification authority for its aircraft and pilots/operators, consistent with authority provided in Title 10 of the US Code.

DoD's UAS NAS access methodology uses an incremental approach to provide DoD UAS critical access to a given operations profile prior to implementing a full dynamic operations solution. DoD's immediate focus is gaining near-term mission-critical access while simultaneously working toward far-term routine NAS access. DoD's efforts will have positive affordability effects by championing utilization of UAS within the NAS. This progress will be accomplished through policy and procedural changes as well as technology and standards development and is thoroughly outlined in the AI Plan. The end state is routine NAS access comparable to manned aircraft for all DoD UAS operational, training, and support missions.

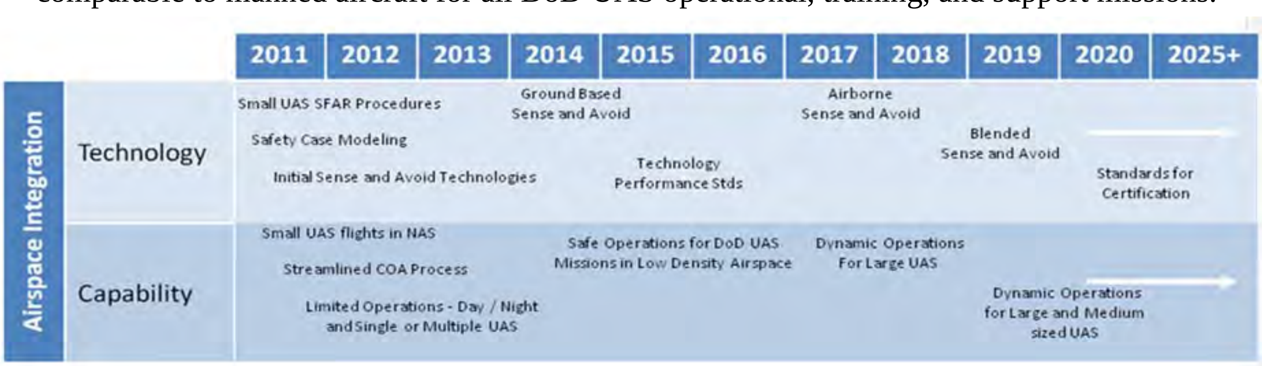


Figure 14. UAS NAS Roadmap.

7 COMMUNICATIONS

> "Ongoing operations in Southwest Asia continue to drive the voracious demand for pilots, support personnel and bandwidth above all"
>
> *– Col. J.R. Gear, USAF, speaking at recent C4ISR Journal Conference in Washington.*

7.1 Functional Description

DoD unmanned systems need a process for operational control and mission data distribution, especially for nonautonomous systems. For some ground and maritime systems, these types of exchanges of information can use a cable for the transmission path, but for highly mobile unmanned operations, the exchange is more likely to use signals sent across the electromagnetic spectrum (EMS) or by other means (e.g., acoustical or optical). The EMS is highly regulated at the national[19] and international[20] levels. While numerous over-the-air communication systems have been designed, built, and fielded and have performed reasonably well, others have been fielded in a noncompliant status and have not met difficult operational constraints.

DoD's desire is to operate unmanned systems in theater or within the United States and its possessions so that communication constraints do not adversely affect successful mission execution. Specifically, DoD must significantly improve communication transmission efficiencies; attain better bandwidth efficiencies; increase transmitter and receiver efficiencies; and acquire communications systems that are of less size and weight, require less power, and provide more efficient cooling to operate.

The operational employment of Unmanned Aircraft Systems requires access to a range of SATCOM capabilities. Planning and budgeting for UAS operations must take into account realistic assessments of projected SATCOM bandwidth (both military and commercial) in a range of operational scenarios. Investments in UAS systems must be matched with appropriate investments in the military and commercial SATCOM capabilities that are required to support UAS operations.

7.2 Today's State

The state of unmanned systems communication systems differs greatly among the air, ground, and maritime environments. In supporting operations in OIF, Operation New Dawn (OND), and OEF there has been a large number of new sensors and communication systems installed on various fielded unmanned systems. These have significantly increased the amount of data that has been collected, and that is desired to be sent to local and remote warfighters. To

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[19] For the U.S. Government, see the National Telecommunications and Information Administration's *Manual of Regulations and Procedures for Federal Radio Frequency Management*. Washington, DC, January 2008 edition, September 2009 revision (incorporated by reference under 47 CFR 300.1).
[20] International Telecommunication Union (ITU), Radio Regulations, Geneva, Switzerland. 2007 Edition.

get the needed data to the remote warfighters, the DoD pays significant funds to several commercial large data transmission companies. Many current unmanned systems have experienced the impact of frequency congestion, interference from systems operating in adjacent frequency bands, and the physical limits associated with the spectrum that has been made available.

The following paragraphs describe the current communication environments by domain.

7.2.1 Unmanned Ground Systems (UGS)

Until recently, most unmanned systems utilized several radios: one for data, one for video, and sometimes one for voice. Because of congestion, frequency competition, and regulatory challenges in several theaters, many of these communication systems were redesigned to operate at higher frequencies. However, use of these higher frequencies reduced the operational effectiveness in dense foliage and urban areas.

7.2.2 Unmanned Aircraft Systems (UAS)

Small, hand-carried and/or hand-launched systems (e.g., the Raven) utilize LOS communications, while large aircraft (e.g., the Predator, Reaper, Gray Eagle, and Global Hawk) utilize both LOS and BLOS communications, the latter generally using satellite communications.

Initial small UAS (< 20 lbs) communication systems utilize industry analog designs, but most now utilize the Army-developed digital data link (DDL) system.[21] The DDL design incorporates aspects of a software-defined radio with the ability to "field-select"[22] the frequency band in which to operate, the channel frequency within that band, the bandwidth of each channel, and the radiated power level.[23] Larger UAS operating LOS incorporate the common data link (CDL) that has been mandated for use in ISR platforms.

7.2.3 Unmanned Maritime Systems (UMS)

There are unique challenges related to UMS: dealing with the air water interface, transmission loss communicating underwater, and negotiating the dynamics of the sea surface. Intermittent communications are the norm in maritime systems and multispectral capabilities are utilized to meet communications requirements. Primary tradeoffs to be considered when evaluating a mode of communication for a USV or UUV that supports dynamic tasking, querying, and data dissemination include data rate, processing capability, range, detectability, and negotiating the maritime environment. These are of particular concern for the ISR and the

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[21] Developed by the Army's Natick Soldier Research, Development & Engineering Center. An alternative DDL for small UAS is also being developed that could use a version of CDL. NATO has developed STANAG 4660, Interoperable Command and Control Data Link for Unmanned Systems (IC2DL), which is based on the DDL.
[22] This selection process is not by software but by switches. Moving to software control is being considered during a future upgrade of the DDL.
[23] The USAF Cryptographic Modernization Program Office and the Army developed a prototype encryptor for this DDL.

ASW missions when communication is desired without exposing either the sender or receiver to possible hostile interception.[24]

7.3 Problem Statement

There are alarming red flags early in this Roadmap's time horizon regarding the amount of data that future UMS sensors will be collecting. How to best deal with that amount of data and distributing the needed information within that data to the right warfighters at the right time will be a major challenge. Left unchecked, sending all that data to local or remote sites will tax current technology and available funding (e.g., COMSAT links). The DoD needs communication technologies and tactics, techniques, and procedures that overcome these limitations and that are agile, robust, redundant, efficient, and affordable. Those needed technologies are discussed throughout Section **7.4 Way Ahead**. However, improved communication transmission technologies alone cannot achieve the necessary capacity. The DoD must pursue a fundamental shift to a future state where we pre-process the collected data, rapidly pass only critical data on to the warfighters, and then store for later retrieval the remaining data that may be needed.

In addition to achieving these technology advances[25], their application in UMS needs to meld with overall DoD wireless network communication concepts, meet national objectives for unmanned systems, and properly address regulatory policies and their limitations. All this needs to be done early in the requirements development process so those advances can be incorporated within future UMS.

In particular, tomorrow's UMS will need to utilize technical strategies which can more efficiently deal with extremely large data sets. In managing this data, better data compression, encryption and processing algorithms need to be employed in preprocessing, transmission and data fusion. These strategies also need to mandate efficient use of the spectrum, reduce frequency use overhead, allow for data security and ensure improved clarity of the available frequency spectrum. To support DoD's goals, communication systems need to support multiple frequency bands, limited bandwidth, variable modulation schemes, error correction, data encryption, and compression. All this support, of course, needs to be done so that no electromagnetic interference (EMI)[26] is caused within those systems or within other nearby spectrum-dependent systems (SDS).

There are numerous challenges to meeting this goal. First, operating a higher density of unmanned systems within relatively small areas creates increased local data rate demands. Second, size, weight, power and cooling (SWaP-C) are limiting factors on many platforms, for both onboard systems and ground/surface control systems. Third, the fidelity of the communication links must be ensured. Fourth, latency associated with digital systems must be reduced, especially for takeoff and landing of large UAS. These challenges will be exacerbated

[24] U.S. Navy Undersea Dominance Roadmap.
[25] These advances need to include government ownership of critical data and intellectual property to ensure the best return on our research investment.
[26] The development of the resulting on-board and ground stations needs to address EMI hardening and the units tested per MILSTD-464A and MILSTD-461F.

by an expected decrease in available spectrum available due to an increase in the civil[27] uses of spectrum, an objective within the Federal Communications Commission's (FCC's) National Broadband Plan[28]and directed by the White House[29].The challenges in attaining this goal include developing, procuring, testing, and fielding communication systems that can operate with greater effectiveness, efficiency, and flexibility even in congested and adversarial environments.

Spectrum testing in unmanned systems today involves communications across a global environment with various levels of spectrum management. The communication challenges require investment in multiple technologies for leveraging communications across the radio frequencies and ultimately the optical spectrum. The impediments to unmanned systems communications are largely restricted to better use of the spectrum through investment in technologies that expand communication efficiencies. The problem today is largely a physics problem, which increases in complexity exponentially as one considers the air, ground, and maritime domain challenges. The testing of cognitive algorithms that can opportunistically leverage communications facilitating advanced mission oversight or multisystem collaboration remains in its infancy.

7.4 Way Ahead

Current DoD policies and guidance stress the need for new systems[30] to have a balance among improved interoperability; increased agility[31]; greater adaptability; improved spectral efficiency; compliance with U.S. national, host nation, and international spectrum policies[32]; and lower production costs. The ability to update and reconfigure parts of a communication system by software changes (e.g., software-defined radios) has been available for several years. In addition, these systems should conform to a standards-based architecture (e.g., service-orientated architecture) that supports multiple networks to enable rapid and transparent configuration changes without removing the radios from operation. Such multiple-input, multiple-output (MIMO), multicarrier, and multiwaveform capabilities, along with the software control of these functions, are needed within future subsystem developments. Ultimately, it is desired that these reconfiguration changes be done "automatically" so the systems adapt dynamically (Figure 11. Autonomy Roadmap.) in response to sensed changes in the operational environment[33] (> 2020).

The need to support operations in which there are intermittent wireless propagation links has become common place. This support has resulted in increased use of advanced error control coding, MIMO configurations, various path diversity techniques, integrated networking, and data diversity — all to provide improved end-to-end quality of service. Future effectiveness of unmanned communication systems is contingent on continued advancements in antennas,

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[27] Both in CONUS and OCONUS.
[28] FCC's National Broadband Plan, Washington, DC, 2010.
[29] Presidential Memorandum "Unleashing the Wireless Broadband Revolution." June 28, 2010,
[30] This goal includes systems used in networking, communications, electronic warfare, navigation, intelligence, and sensors.
[31] This goal would include assured and secure communications.
[32] See DOD Instruction (DODI) 4650.01, Management and Use of the Electromagnetic Spectrum, Washington, DC, 9 January 2009, and DODI 4630.8, Procedures for Interoperability and Supportability of Information Technology (IT) and National Security Systems (NSS).
[33] Also see Section 5 of this Roadmap.

transmit/receive systems, underwater communications, spectrum considerations, signal processing, network systems, and optical communications. A description of those advancements is given in the following subsections.

> … Reinvigorate the industry's independent research and development and protect the defense industrial base.
>
> *–Under Secretary of Defense Memorandum for Acquisition Professionals, Better Buying Power, September 2010*

7.4.1 Antennas

Communication with highly mobile systems requires high-gain, rugged, and lower cost multidirectional antennas. The larger UAS systems may also use highly focused beams to achieve connectivity with more distant systems.[34] Developments in phased array antennas and "smart" antennas (to include combining signals from multiple antennas) could offer an alternative to traditional dish antennas; however, they require tradeoffs among SWaP-C. DoD and industry will need to continue developing such techniques as multifocused and super-cooled antenna systems. The multi-focused systems would permit multiple users to receive information and not rely on point-to-point systems and subsequent relaying of data via other communication systems to local users.

Future antenna systems need to be able to send and receive signals over a broad range of frequencies. Phased arrays are a viable approach. For SWaP-C and low-profile considerations, phased array antennas need to be conformal (e.g., using metamaterial) that will be molded within the vehicle surfaces. The utilization of common apertures has called for the development of new interference mitigation methodologies that minimize co-site interference effects and improve the potential for achieving simultaneous transmit and receive operations within adjacent frequency bands.

7.4.2 Transmitter/Receiver Systems

Current transmitter solid-state power amplifiers (SSPAs) are typically made with gallium arsenide (GaAs) substrate. Gallium nitride (GaN) SSPAs, currently in development, provide significant advantages over GaAs SSPAs. They offer more than double the efficiency of GaAs amplifiers; they increase the amplifier operational bandwidth; and GaN SSPAs may provide for a wider range of frequency of operation. The high transmit efficiency of GaN systems will also reduce the cooling requirements. In order to achieve some of these benefits, the amplifier designs are being enhanced with adaptive operating point control that adjusts to the instantaneous power being demanded from the amplifier. This enhancement significantly reduces the average prime power required by the amplifier by allowing it to effectively turn itself off when not in use, yet adjusting to maintain proper conditions to ensure minimal distortion at higher instantaneous powers. The GaN technologies are currently available for selected frequency bands and will soon

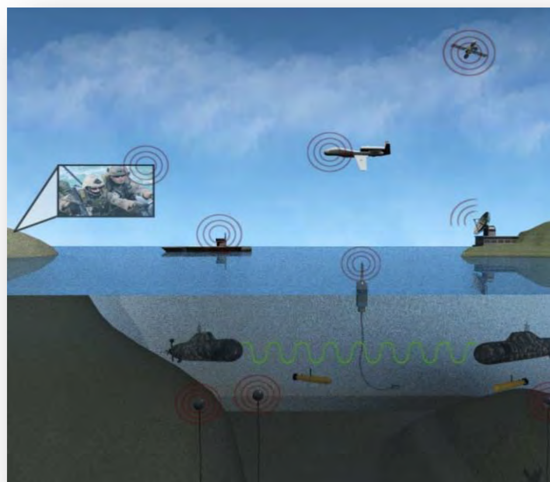
[34] Global positioning system (GPS) has been used to aid in this connectivity.

be available for fielding (2014). The amplifiers may also utilize signal-processing-based signal predistortion techniques to compensate for the basic nonlinearity of the amplifier's transfer characteristics.

Instantaneous bandwidth performance and analog-to-digital converter sampling speeds have continued to improve year after year.[35] In addition, improvements in integrated chip fabrication methods have allowed for significant miniaturization and reductions in part counts and for various transmit/receive and antenna functions and components to be integrated on a single chip (2013). Fiber optics has been used to speed up the data and signal transfers from and to the antenna and the signal processing hardware (2012).[36] Microminiature mechanical device developments should provide smaller size, more flexibility, and greater performance in receiver designs[37] (2015). Future developments are expected to provide improvements in reliability and fabrication yields, reduced thermal characteristics, reduced integration complexity, and lower production costs.

7.4.3 Underwater Communications

Ocean dynamics challenge underwater and surface communications and are unique to UUVs and USVs. These systems gain efficiency and effectiveness with real-time, two-way communications that do not undermine mission accomplishment. The Navy's *Undersea Dominance Roadmap* (under development) will identify current and future architectures to link UUVs, distributed netted systems, and tactical platforms. Future developments described in that roadmap will leverage existing technologies and potential new capabilities that will come through the Office of Naval Research S&T research and development efforts.



7.4.4 Spectrum Considerations

U.S. military operations are now occurring in many parts of the world where adequate spectrum is not available. There is a significant increase in the numbers of SDS being deployed by the United States, our partners, and our coalition forces to address current and expected future

[35] Lundberg, Kent H., *High-Speed Analog-to-Digital Converter Survey*, MIT Press, 2002.
[36] See the DARPA Optical RF Communications Adjunct and the Office of Naval Research's Enabling Capability programs. This application is more for ground-based systems than for airborne systems. This use also significantly minimizes the signal loss and allows more advantageous placement of selected components.
[37] C. T.-C. Nguyen, "Microelectromechanical devices for wireless communications (invited)," *Proceedings*, 1998 IEEE International Micro Electro Mechanical Systems Workshop, Heidelberg, Germany, Jan. 25-29, 1998, pp. 1-7.

mission areas. In addition, these SDS collect more information, and missions often require greater bandwidths to send their information directly to warfighters. This latter consideration has been seen within OEF missions where new ISR UAS have included wide area surveillance sensors; alternative spectrum bands have been identified[38] to help address the wider bandwidths needed by those systems. Also, mission areas are becoming more spectrally "noisy" because of increasingly cluttered and hostile spectrum environments. As such, a continual demand for improved spectrum efficiency and effectiveness is being placed on all DoD SDS.[39] All unmanned systems must complete during their development process a spectrum supportability and risk assessment in accordance with DODI 4650.01 to identify and mitigate regulatory, technical, and operational spectrum supportability. Because national and international spectrum rules and policies can rapidly change,[40] developers should maintain a close liaison with appropriate DoD spectrum offices before finalizing communication system designs.

The use of LOS datalinks also supports missions where there is a denial of or impaired service to SATCOM systems. Under such conditions, the demand for LOS spectrum will be extended to support the need for improved spectrum use efficiency and effectiveness.

The Defense Advanced Research Projects Agency's (DARPA's) Next Generation (XG) project and its follow-on Wireless Network after Next (WNaN) program demonstrated the feasibility of dynamic spectrum access (DSA). DSA offers the ability to change frequency band use based on other adjacent SDS actual use and nonuse of certain bands. The Joint Tactical Radio System (JTRS) program is investigating the feasibility of integrating DSA technologies into its system. The U.S. Army is also considering having WNaN become part of an Army program of record. However, a recent USAF Scientific Advisory Board study said that DSA is far from being proven technology. Developmental challenges include susceptibility to countermeasures, costs of integrating with existing systems, developing standards (including regulatory aspects), and co-site interference (2015).

Alternative technology advances should aid in the spectral efficiency challenge to include internal and external EMI mitigation advances such as coherent signal cancellation, space-time adaptive processing, polarization diversity, and adaptive digital beam forming.

[38] OASD NII memo dated March 22, 2011 Subject: Department of Defense (DoD) Common Data Link (CDL) Usage in Operation Enduring Freedom (OEF) Theater

[39] All new and modified SDS programs now need to conduct a spectrum supportability and risk assessment prior to Milestone B (source: DODI 4650.01).

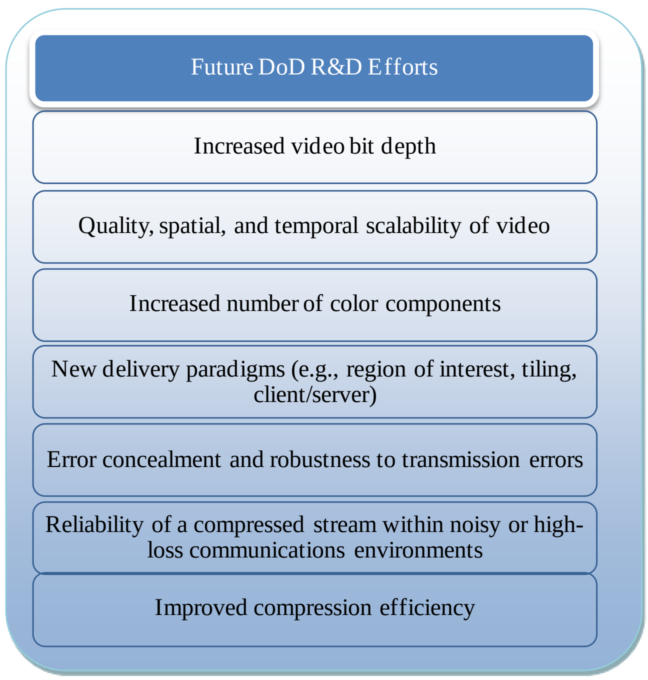
[40] Relatively near-term spectrum usage changes could come from the ITU and its 2011 Worldwide Radiocommunication Conference (WRC); UAS spectrum use is a conference agenda item. Changes in frequency band usage for UAS may also come from the FAA and the ICAO as part of the UAS operations in the NAS airspace and in other nation-states' airspace.

7.4.5 Communications and Signal Processing

7.4.5.1 RF Waveforms

All ISR systems are to use the CDL waveform specification[41] whenever possible.[42] A mini-CDL system[43] is finishing development to allow CDL usage within smaller platforms than were possible in the past. Candidate future CDL waveform developments include adding a "dial-a-rate" capability for transmission speeds (with multiple bits-per-hertz and operating within the gigabit-per-second range) and a more efficient forward error correction (FEC) coding (both 2014). Also, several UAS program offices are pursuing such performance advances as more efficient CDL waveforms, operation in additional frequency bands, expanded communications security,[44] low probability of intercept (LPI) or low probability of detection (LPD), improved anti-jam, and greater link throughput. Corresponding improvements in surface and ground stations that receive the CDL signals have also been or are being made. There have also been significant efforts to improve commonality of these systems through the UAS Task Force and its I-IPT.[45]

Future CDL improvements will include, as feasible, the incorporation of advancements being offered by DARPA, industry, and academia. Four of the most appropriate DARPA programs that are being closely followed are the DARPA Interference Multiple Access and Disruption Tolerant Networking programs.



7.4.5.2 Preprocessing

Considering the anticipated large amounts of data projected to be collected by unmanned systems in an environment of limited bandwidth capability, one challenge is determining how much of that data needs to be sent back in near real time to a ground station. There is ongoing interest in addressing how best to select portions of images and to track those portions over time and send back "just" those selected images in near real time. These selection activities are currently being developed within classified TPED programs. As these activities progress, they should be applied in preprocessing efforts onboard

[41] These developments follow DODI 4630.09, DoD Wireless Communications Waveform Development and Management. The currently approved version is Standard CDL (STD-CDL) Rev H.
[42] The main reason for nonuse would be SWaP-C issues.
[43] This effort mostly focused on SWaP-C issues.
[44] Two cryptographic solutions (one classified and one unclassified) are used currently.
[45] See Section 4 of this Roadmap.

unmanned systems. Improved preprocessing must be accompanied by sensor and processor miniaturization to reduce SWaP-C so as to maintain the persistent nature of UMS.

7.4.5.3 Compression

Compression techniques have tremendous potential to reduce bandwidth requirements, resulting in lower operating costs and increased operational flexibility. For example, FMV, synthetic aperture radar (SAR), inverted SAR (ISAR), and multispectral images can generate high bandwidth requirements (> 360 Mbit/s data rates). When compressed, the datalink bandwidth requirement could be in the range of only 1 to 30 Mbit/s.[46] Current compression techniques are described in the motion imagery systems matrix (MISM).[47] This matrix defines a recommended practice for the simple identification of broad categories of motion imagery systems. The intent of the MISM is to give user communities an easy-to-use, common shorthand reference language to describe the fundamental technical capabilities of DoD/Intelligence Community (IC)/National System for Geospatial Intelligence (NSG) motion imagery systems. The video quality needed for unmanned systems would nominally be MISM levels 4M/4H and 3M/3H. Currently the H.264 standard, which is firmly engrained in the commercial market,[48] offers twice the performance as Motion Picture Experts Group-2 standard (MPEG-2), and advanced encoding options will give even greater improvements[49] (albeit with potentially increased encoder latency).[50] The goal of the United Nations' ITU is for the H.265 standard to provide a chosen quality level at half the bit rate of H.264 (2018). For unmanned applications, future research and development should be undertaken by DoD and industry within areas depicted in the graphic on the right.

Beyond technical compression of all the collected data, there are logical advances that could reduce the amount of information that needs to be sent. This would include incorporation of logical bases for "just" replacing old information about a target's position with a more recent update, but not resending the unchanging background around the target.

> In addition to performance enhancements, compression techniques have tremendous potential to reduce bandwidth requirements and thereby reduce operating costs.

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[46] Operational needs should determine the data rate that should be sent. Commanders in the field should be encouraged to require the lowest possible resolution and other parameters that meet their needs.
[47] See Motion Imagery Standards Profile (MISP) Recommended Practice 9720d, MISM, Standard Definition Motion Imagery.
[48] It is widely used within Blu-ray and digital video disk (DVD) systems.
[49] Over the past several decades, each generation of standardized video compression has provided a halving of the required bit rate for a given quality level relative to the prior generation.
[50] The latency introduced by some compression schemes can be so great that data links using such compressions cannot be utilized during such critical times as takeoffs, landings, and weapon launches.

7.4.5.4 Encryption

Unmanned systems incorporation of data encryption includes National Security Agency (NSA) Type 1 (for protection of classified and unclassified information) or Federal Information Processing Standards (FIPS) Publication 140-2 certified solutions (for sensitive but unclassified information).[51] Several encryption solutions exist (e.g., Type 1 systems) for protection of unmanned systems communications (see DODI 4660). Numerous other policies and initiatives are under development within the NSA to significantly streamline the certification processes and reduce costs.[52] Future encryption solutions (2015) will inherently contain Suite B (public) encryption algorithms[53] to allow for secure classified information sharing with coalition and friendly forces. Additionally, an increasing number of encryption solutions will be based on such concepts as open standards for remote management; dynamic group keying (to support machine-to-machine information exchanges), common radio and system agnostic cryptographic interfaces (e.g., improving cryptographic component reuse and portability); software-based solutions for protection of classified data;[54] multifunctional single-chip data-in-transit and data-at-rest encryption; and single-chip all-encapsulated encryption modules (e.g., encrypt/decrypt/random key generation/key management).

7.4.5.5 Multiple Input, Multiple Output (MIMO) Systems

MIMO is a proven technology and is currently being used in commercial fourth generation (4G) wireless systems which have standards calling for a minimum of 100 Mbps for train and car speeds and 1 Gbps for stationary and walking speed. [55] MIMO combines information theory, FEC coding, signal processing, propagation theory, and consequently the mathematics behind MIMO and space-time coding is complicated. MIMO would utilize multiple paths (although not necessarily independent) with lower data rates on each path; apply space-time coding and capacity optimization to achieve a total high data rate mission; apply power saving to jammer margin; and evaluate performance in benign and stressed conditions.

With further improvements in E-discovery, interface design, and adaptive protocols, self-forming and self-healing mesh networks may enable unmanned systems to operate in multi-platform, multi-sensor type networks.

7.4.5.6 Protected Communications

In general, unmanned systems have been predominantly operated in benign environments. However, efforts are addressing improvements that are required to enable such systems to have assured and secure communications when operating in contested environments. These efforts leverage LPI, LPD, and Anti Jamming (AJ) activities that are underway in other communication systems developments. When moving UMS operations into contentious environments, a

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[51] Source: Memorandum from NII, Subject: Cryptographic Methods for Protection of Unmanned Aircraft (UAS) Wireless Communications, 6 August 2003.
[52] Management Directive 17, (U) Requirements for the Pilot Implementation to Develop Information Assurance Government Off-The-Shelf (GOTS) Secret and Below (SAB) Products and Commercial Solutions for Classified.
[53] CNSSP 15, dated March 2010.
[54] Ongoing efforts by NSA/I851.
[55] The conditions in UAS applications are much different than those for commercial cell phones.

classified System Threat Assessment Report needs to be developed such that the appropriate LPI, LPD and AJ techniques are selected for incorporation into the system's design. LPD generally seeks to hide specific mission activities and involves techniques such as low power, spread spectrum, pulsed transmissions and/or directional antennas. Certain aspects of DSA could also benefit LPD. A key technique for LPI is the use of bit cover sequences within waveforms. AJ techniques include incorporating randomization at the protocol level and frequency hopping. Some aspects of DSA software implementation could offer some AJ protection.

7.4.6 Network Systems

Networking of multiple unmanned systems may be necessary to better ensure connectivity of the systems in non-LOS, urban, hostile, and/or noisy EMS environments to relay or transfer the collected information. One such concept under development is within the DARPA's LANdroids program,[56] which calls for the deployment of small, inexpensive, smart robotic radio network relay nodes that can leverage their mobility to coordinate and move autonomously. It seeks to demonstrate the capabilities of self-configuration, self-optimization, self-healing, tethering, and power management. Another concept would be the application of service-orientated architecture approaches to future network configurations.

7.4.7 Optical Communications

The application of lasers in unmanned systems communications could provide increased target detection capabilities, improved anti-jam performance, and decreased EMI within the communication subsystem. Optical communication systems are hampered by atmospheric absorption challenges, yet they offer far greater bandwidth (measured in gigabits-per-second) capabilities. LOS optical links have been successfully demonstrated at link ranges in excess of 50 km. Applications could apply to fixed locations and in air-to-air and ship-to-ship scenarios. Theoretical estimates indicate that air-to-ground links are feasible at rates up to 100 Mbit/s for link slant ranges up to 100 km, depending upon atmospheric conditions. Due to the extreme narrow beamwidth of such systems, maintaining pointing accuracy to and from a moving unmanned system will be a major challenge (> 2020).

7.5 Future Trends

Based on the force multiplier that unmanned systems have provided to our combat troops, it is expected that there will be a continued and increasing demand for supported capabilities communication systems. Those demands will include such capabilities as a single operator conducting more real-time analysis of multiple situations, while the unmanned system performs many of its assigned functions autonomously. Future communications equipment will need to be simple plug-and-play payloads that are easily, quickly, and cost-effectively modified, updated, and/or upgraded.

[56] Source: http://www.darpa.mil/ipto/programs/ld/ld.asp.

> Future communications equipment will need to be simple plug-and-play payloads that are easily, quickly, and cost-effectively modified, updated, and/or upgraded.

7.6 Summary

There is tremendous worldwide competition for a finite amount of bandwidth. Concurrently, there is an increased demand for our unmanned systems to provide greater resolution, more persistent coverage, and continuous information flow. Technology supporting physical and software advances, and a fundamental shift in how we process and move vast quantities of data must be used to help overcome these conflicting requirements. Figure 15 provides a glimpse into the future capability and technologies we can expect throughout the course of this Roadmap.

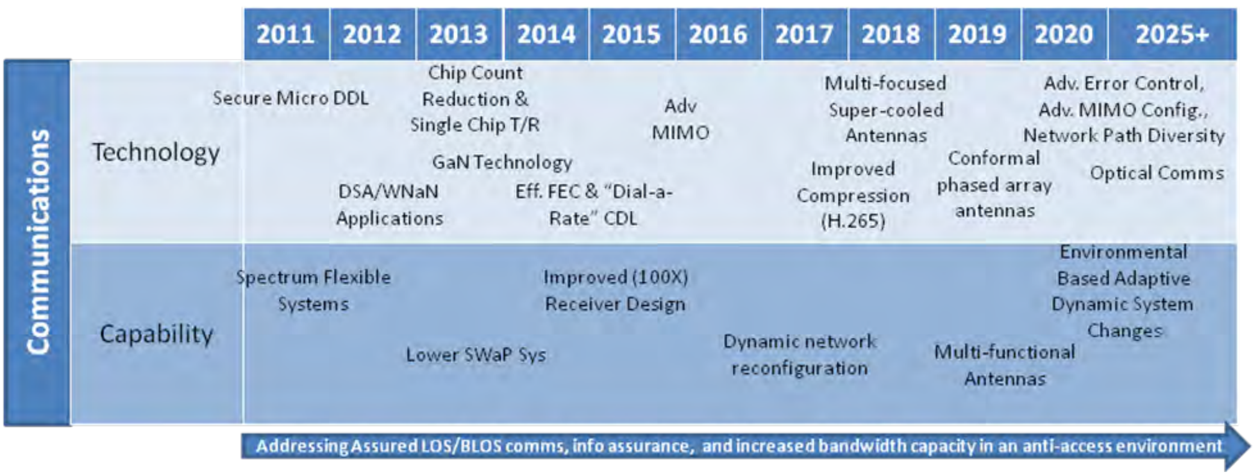

Figure 15. Communications Roadmap.

8 TRAINING

8.1 Functional Description

Training is a critical link in delivering warfighter capability. DoD can acquire and deliver the most technologically advanced piece of machinery, but if the operators, maintainers, and support personnel are not properly trained, there is no warfighting capability. The criticality of this fact is emphasized by the requirement for acquisition program managers to "work with the training community to develop options for individual, collective, and joint training" as part of the acquisition process.[57]

Training is a learning process that involves the acquisition of knowledge, sharpening of skills, concepts and rules, or changing of attitudes and behaviors to enhance performance. Once initial training is complete, proficiency is maintained through continuation and Joint training. Unmanned systems present a unique training challenge due to the following factors:

- Availability of training areas/NAS integration.
- Frequency spectrum management.
- The rapid proliferation of numbers and types of unmanned systems in response to wartime demand.
- Differing organizational perspectives on vehicle operator qualifications, sensor operator qualifications, and support personnel requirements across the growing number of systems in all classes of UAS, UGS, and UMS.
- The reality that most USAF day-to-day continuation training is accomplished under in-theater combat conditions due to the high demand for UAS assets in real-world contingencies. This trend provides limited opportunity for the USAF to integrate its unmanned systems in pre-deployment training as the Army and USMC routinely do.
- Lack of operator interoperability and universal design standards for unmanned systems control stations.
- Lack of formalized joint tactics across the Services.

8.2 Today's State

As unmanned systems have matured and acquisition programs of record have emerged in all Services, a concerted effort has been made to ensure, wherever practical and possible, that the Services share logistics costs and burdens to include training and training systems. To date, many success stories can serve as a template for moving toward the vision of maximum joint training standard(s) for unmanned systems:

- USMC and Army personnel operate a joint Shadow UAS qualification course at the Army's training facility in Fort Huachuca, Arizona. While the Navy does not operate

[57] DoD Instruction 5000.02 Operation of the Defense Acquisition System, December 8, 2008, p.61.

Shadows, Navy operators and maintainers were asked to help bridge a high-priority capabilities gap. This task was accomplished with no change in training hardware and software, simulation, or practical hands-on training. Navy personnel successfully deployed the Shadow system.

- The Chief of Staff of the Air Force and the Chief of Naval Operations signed a MoA to better utilize joint efficiencies in the Air Force Global Hawk and the Navy BAMS UAS programs. The goals of the working group are transparency between systems and a common work environment for both USAF and Navy operators.
- Army and Navy/USMC personnel share Raven B training and equipment, including maintenance requirements and GCSs.
- The JUAS COE[58] developed joint CONOPS, training qualification standards, and Tactics, Techniques, and Procedures for UAS.

Despite these success stories, given the DoD mandate to maximize training procedures and standardization for unmanned systems, the current state of unmanned systems training is still very much a work in progress.

The need for a comprehensive UAS training strategy was highlighted in UAS training workshops held in July and November 2009, hosted by the Office of the Deputy Assistant Secretary of Defense for Readiness, Directorate for Training Readiness and Strategy (ODASD(R)TR&S). The workshops were attended by all four Services, CCDRs, OSD, and Joint organizations involved with UAS issues. Additionally, a recent Government

> Provide soldiers and leaders the ability to excel in a challenging and increasingly complex future operating environment by developing tools and technologies that enable more efficient and effective training through live, virtual, constructive and mixed venues. Future training must enable the future force to impart more skills, faster, at lower cost and with greater retention than currently achievable. Soldiers and units must be able to be trained using non-traditional home station training techniques and technology and train prior to employment. Future training must enhance and account for individual proficiencies and learning rates (i.e. outcome based training). Future training and leader development must be completely adaptable and scalable to cover the full spectrum of operational challenges facing the Soldier.
>
> *– Capability Gap/Deficiencies, Robotic Systems Joint Project Office Unmanned Ground Systems Roadmap, July 2009*

Accountability Office report recognized the lack of UAS training planning and called for the development of a DOD results-oriented strategy to resolve challenges that affect the ability to train personnel for UAS operations.[59]

[58] JCOE is being disbanded June 2011 and its tasks are being transferred to the Joint Staff and UAS Task Force.

8.3 Problem Statement

As forces drawdown in theater and redeploy, the Services will require comprehensive continuation and Joint-forces training in the peacetime environment at beddown and selected Joint-training locations. Failure to prepare for this eventuality will result in a loss of combat gained experience.

8.4 Way Ahead

The ODASD(R)TRS is leading efforts to develop a comprehensive DoD UAS training strategy. The strategy will leverage the skills and expertise of each organization and build on foundational efforts already completed or underway within the Services. The study will investigate and assess the adequacy of existing and forecast joint, Service, and CCDR UAS plans and programs that identify and describe qualification, continuation, and joint training requirements and CONOPS. The strategy will identify and describe individual, unit, and large force training requirements of all groups of UAS. The result will be a UAS Training Roadmap that guides UAS training shortfall and mitigation analyses, provides UAS training recommendations, and proposes investment considerations for the UAS community. The UAS Training Roadmap will serve as a companion piece to this Unmanned Systems Roadmap to provide a total look at efforts related to delivering UAS capabilities to the warfighter.

Intuitively, some issues that will need to be addressed in the future include:

Policy: As attention shifts more towards day-to-day continuation training and UAS are further integrated into the NAS, unforeseen disconnects in the ability to train will need to be addressed in policy.

Education: UAS need to be habitually integrated into the kill chain in training scenarios. Commanders must be educated on the use of UAS as combat resources, and learn how to train with these relatively new assets. Tactical, Operational, and Strategic level UAS and ISR doctrine should be included in appropriate professional military education courses of instruction. Issues involving operator currency, flight minimums, and continuation training requirements must be learned and opportunities to train must be must be emphasized during home station training, combined exercises, and Joint Combined Training Center rotations.

Training Automation and Simulation: Rapidly expanding weapons systems capability requires associated expansion in training simulation. This expansion will need improved simulation fidelity and integration with live platforms for both effective/efficient use of resources. This will require improvements in training environments and classroom courseware.

Basing and Acquisition: As training requirements are defined, existing capabilities at proposed basing locations must be assessed against that which must be acquired to provide effective training.

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[59] GAO-10-331, UNMANNED AIRCRAFT SYSTEMS: Comprehensive Planning and a Results-Oriented Training Strategy Are Needed to Support Growing Inventories, March 2010.

> … UAS operators advised that the use of simulation is critical to their preparation for combat. UAS simulation is so accurate and realistic that, specifically for the Shadow UAS, it is hard to tell the difference between the simulator and actual flight.
>
> – *SFC Brian Miller, UAS Standardization NCO, Directorate of Evaluation and Standards, USAACE, Fort Rucker*
>
> The majority of flight training is simulation.
>
> – *SSG Brian Morton, 15W UAS Instructor/Standardization NCO, UAS Training Battalion, Fort Huachuca*

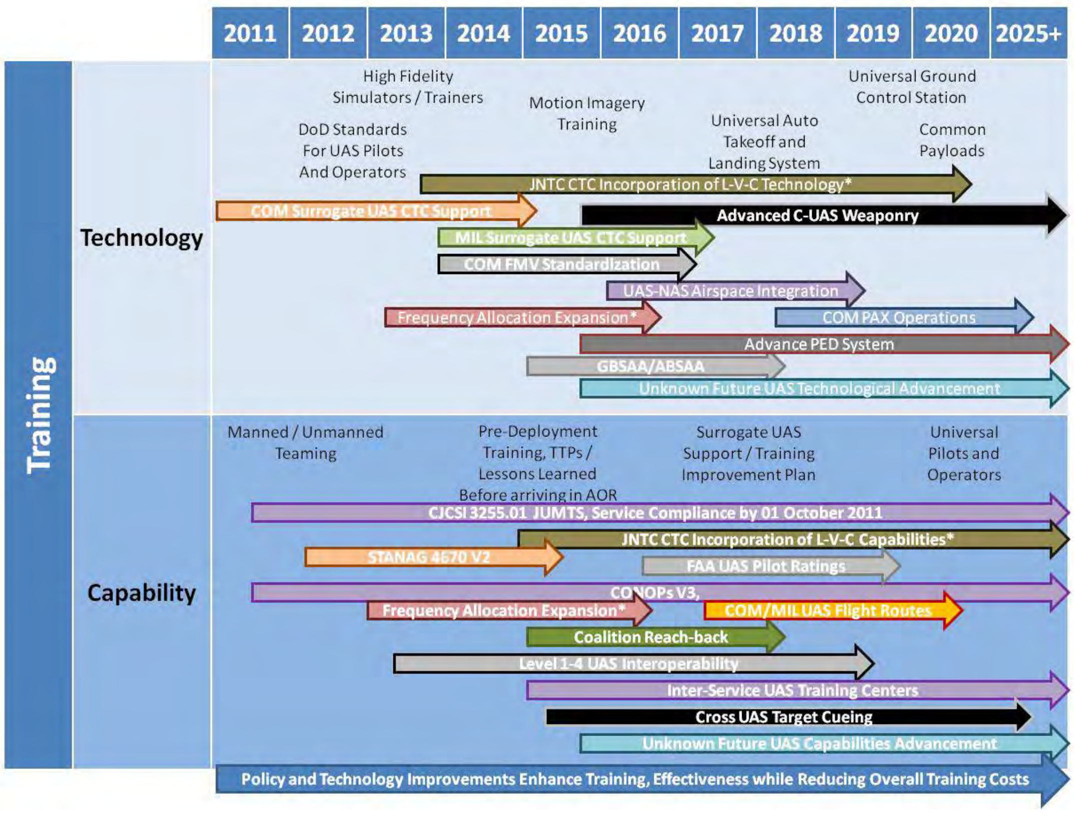

Figure 16. Training Timeline is notional. A DoD UAS Training Strategy is currently in development that will add specificity once developed.

9 PROPULSION AND POWER

9.1 Functional Description

The dramatic increase in the development and deployment of unmanned systems across the entire spectrum of air, ground, and maritime mission requirements has led to a concurrent increase in the demand for efficient, powerful, often portable, and logistically supportable solutions for unmanned system propulsion and power plant requirements.

For the purpose of this section, propulsion and power consist of the prime power to provide thrust and electrical power conversion, management, and distribution necessary for the operation of the electrically driven subsystems required to perform an unmanned vehicle's mission.

9.2 Today's State

A wide array of propulsion systems is used in unmanned systems, including combustion engines powered by heavy fuel or gasoline, jet engines, electric systems, fuel cells, solar power, and hybrid power systems. These propulsion systems can be divided into three groups according to vehicle size and mission: turbine engines, internal combustion, and electrical. The thresholds are not simple or clean cut, but are highly dependent on mission goals. Some of the parameters taken into consideration to determine the optimum propulsion system include size, weight, airflow, range, efficiency, and speed. Similarly, numerous power systems are in use, including batteries, engine-driven generators, solar power and hybrid systems.

The T&E of propulsion and power is critical as we consider a world of declining energy reserves and the strategic initiatives in alternative energy being made by the DoD.

9.3 Problem Statement

Endurance is perhaps one of the most compelling aspects of unmanned systems. While power and propulsion systems are much improved over comparable manned systems, the search continues for even more efficient systems to provide greater endurance, speed and range such as the X-51A Scram Jet shown in Figure 17 preparing for first flight.

Figure 17. X-51A Scram Jet.

9.4 Way Ahead

9.4.1 Propulsion

> A primary long-term goal in aircraft propulsion is to reduce system specific fuel consumption by more than 30 percent over (current) gas turbine engines…. Technical challenges being pursued include efficiency, high-overall-pressure-ratio compression systems; variable-cycle engine technologies; advanced high-temperature materials and more effective turbine blade cooling; and techniques to more efficiently recuperate energy while satisfying thermal and power requirements.
>
> *– The National Plan for Aeronautics Research and Development and Related Infrastructure*

These challenges are currently being addressed for UAS applications under the highly efficient embedded turbine engine (HEETE) and efficient small-scale propulsion (ESSP) products, which are part of the Versatile Affordable Advanced Turbine Engines (VAATE) Program.

HEETE will demonstrate engine technologies that enable fuel-efficient, subsonic propulsion that supports future extreme endurance and range requirements with embedded engines incorporating complex inlets and exhausts. Covering the thrust class of 20,000 to 35,000 lbs, HEETE has two challenges: packing a high-bypass engine internally and delivering large amounts of electrical power regardless of throttle or flight condition. The HEETE design provides very small, high-powered cores to enable high bypass within the diameter constraints of an internally packaged engine. The propulsive efficiency is provided by highly efficient fans designed with the distortion tolerance needed to run behind complex inlets. The HEETE cores run at impressive pressure ratios, greater than 2.3 times the current state-of-the-art, and such ratios enable high tolerance of auxiliary power at high-altitude, long-endurance (HALE) altitudes. See Figure 18 HEETE cutaway view.

Figure 18. Highly Efficient Embedded Turbine Engine (HEETE).

ESSP will cover a full spectrum of technologies for propulsion systems for vehicles ranging from 100 to 2500 lbs. These products promise game-changing system capabilities. The S&T challenge to meet the ESSP goals is the simultaneous combination of high power density with high efficiency (low specific fuel consumption) in a design space not typically addressed by either gas turbine or piston engine systems (see Figure 19. Efficient Small-Scale Propulsion (ESSP).).

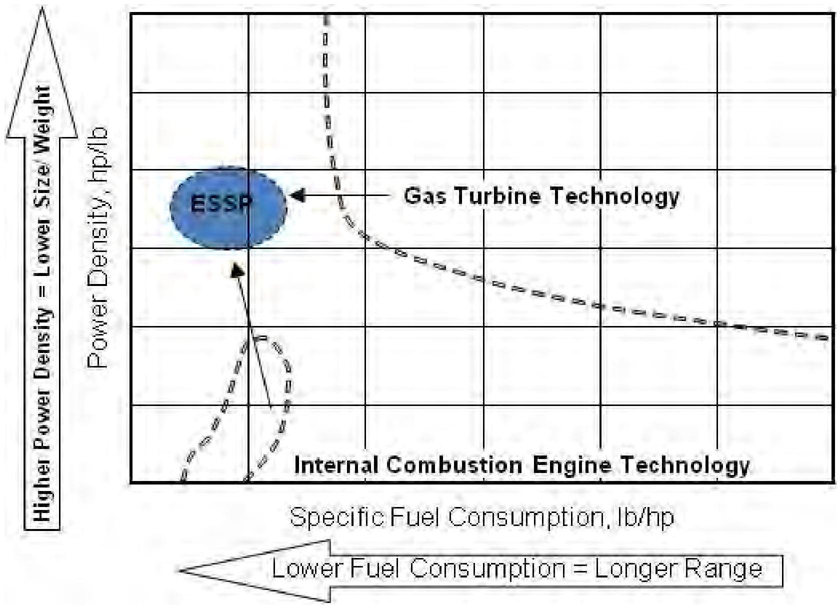

Figure 19. Efficient Small-Scale Propulsion (ESSP).

ESSP will conduct various demonstrations leading to reduced specific fuel consumption (SFC), increased power density, and a heavy fuel consumption capability. These demonstrations include a ducted fan, a nutating engine, a heavy fuel engine conversion, and a recuperator. ESSP is also designing and rig-testing high pressure ratio compressors and high temperature capable turbine concepts aimed at long-term capability.

The ducted fan is the most complex of the near-term demonstrations. The two main technologies to be demonstrated are the high-bypass geared ducted fan and the variable turbine nozzle. The test demonstrates the capability to run the high-bypass ducted fan with airflow from two different distributed core gas generators for maximum power during takeoff and maneuvering and then turning off one core gas generator, as a variable cycle feature, at cruise to cut the fuel consumption (conventional high-bypass turbofans would have to pull back the power setting to attain cruise condition, and this method would decrease engine speed, reduce the pressure ratio, and decrease component efficiencies resulting in increased SFC). The remaining core gas generator used to drive the ducted fan at cruise condition continues to operate at its design point for best cycle SFC. The variable turbine nozzle matches the airflow changes to maintain efficient turbine performance and drive the ducted fan.

The nutating disk engine leverages small business innovation research (SBIR) contracts for both the 4-inch and 8-inch disk engines. Both engines utilize the OSD SBIR-derived advanced microcomponents to enable engine performance potential. The major technical challenges are the

development of micro-fuel injectors and radial engine seals and the understanding of the thermodynamics process. Both sizes of disk engine have undergone initial testing and show a significant increase in power density, to 1.38. The nutating disk is scalable to multiple UAV platforms by scaling the disk size.

The heavy fuel conversion engine, i.e., the Rotax used in the Predator, runs on aviation gasoline (AvGas, 100 octane). The Rotax concept demonstration is aimed at running the engine initially with lower octane fuels and ultimately with JP-8 heavy fuel. Engine testing has been completed successfully with 70 octane fuel. Although octane level is not specified for JP-8 fuel, fuel analysis to date has shown variations between a 20 to 50 octane level. Testing is on-going to demonstrate the operation of the Rotax engine on JP-8 fuel with targeted completion by the end of 2010. In parallel, there are SBIR efforts working to convert the Shadow UEL AR-741 engine to JP-8 fuel. Conversion efforts are aimed at maintaining engine performance levels while operating with JP-8 fuel.

The WTS126 turbo generator, developed by Williams International to drive the General Motors electric car, has a highly efficient recuperator, but is too heavy and large for installation into a flight vehicle. VAATE II studies indicated that a less efficient recuperator appeared to be the best balance among performance, size, and weight for a flight vehicle application. The WTS126 is an alternative heavy fuel propulsion system candidate for the Shadow. Testing and evaluation of the baseline WTS126 and the version with the less efficient flight weight recuperator are both underway.

For smaller platform applications, fuel cells offer an attractive alternative for internal combustion engines as field power generators, ground vehicle and aircraft auxiliary power units (APUs), and primary power units for small UAS. Fuel cells are devices that electrochemically combine fuel and air to produce high-quality electrical power. Because these systems do not generate power via combustion processes, they offer significantly lower SFC rates relative to advanced heavy fuel engines or diesel power generators (see Figure 20).

Solid oxide fuel cell (SOFC) systems represent a compelling power system option due to their high efficiencies, fuel flexibility, and low audible signature. Compared to other fuel cell approaches, the thermal environment and conductivity mechanism in SOFCs allow for a considerable improvement in fuel tolerance and provide a path forward for electrochemical logistic fuel operation.

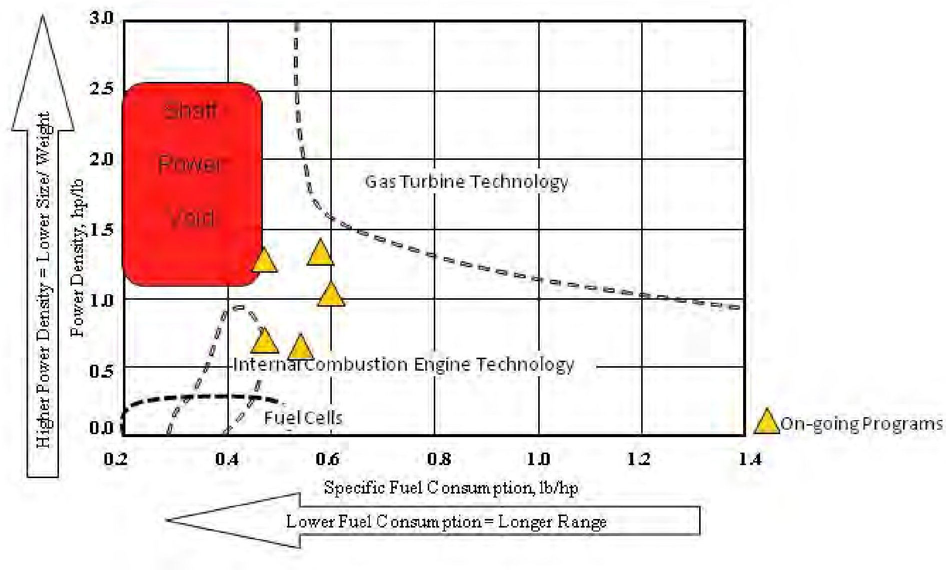

Figure 20. Fuel Cell Efficiency.

9.4.2 Power

Power sources are critical enablers for all of the desired unmanned systems capabilities. Improved power sources will have to be compact, lightweight, and reliable; provide enough power for the desired mission; and satisfy a full range of environmental and safety requirements. Design of power sources must be optimized for specific platforms and use profiles. Depending on the platform and mission requirements, applicable technologies may include energy harvesting (e.g., photovoltaic), electrical energy storage devices, fuel cells, and generators. It may be attractive to hybridize two or more of these technologies depending on the expected use profile. To implement these hybrid systems, the development of the proper control schemes must also be conducted. Recently, there has been a lot of effort invested to improve the power density of power generation systems with very good progress, but work is still needed to improve other power systems critical metrics. Some of these needed metrics and improvements are life, reliability, efficiency, optimized performance over varying engine speed, wide temperature range, production variability, control strategy, and parameters that capture the fact that unmanned subsystems typically do not have the redundancy of manned systems. Early scrutiny of the vehicle design will lead to improved power management. Form factor, materials, autonomy in sensor usage and route planning, and consideration of the undersea physical environment will minimize the energy demands and give back energy to extend the endurance or meet other mission goals.

Advances in mission equipment are providing much greater capabilities, but at a cost of greater demand for electric power, which results in greater power extraction from the engine. Power-sharing architectures allow for tailoring the source of power generation to minimize the cost in fuel burn. For example, if low-pressure (LP) power extraction is more economical than high-pressure (HP) power extraction, then the SSPCs can be turned on to power the bus that was previously powered by the HP-driven generator. Engine power extraction technologies related to power sharing between the HP spool and LP spool promise to provide significant benefit to

bridging the gap between the platform power requirements and the engine power extraction limitations. Additionally, LP power extraction promises to provide improvements to SFC for overall air vehicle energy efficiency. Some of the key technologies needed to implement a power-sharing architecture are reliable power management control logics, high-power high-speed solid-state power controllers (SSPCs), a modulating generator control unit (GCU), and high-capacity electrical accumulator units (EAUs).

The HP GCU can be used to reduce the HP generator output and thus in a similar manner reduce the load on the HP spool to allow the LP generator to fulfill the power demand. The EAUs will be used to support radar peak-power demands and the power demands of short-duration, defensive-directed energy weapons.

9.4.3 Future Opportunity

Work is still needed to demonstrate the shaft power void. However, the large-engine approach of high overall pressure ratios (going to typical small-engine-corrected flow levels) is not available to small engines because of the physical size constraints of turbomachinary. Therefore, nontraditional configurations need to be emphasized to achieve the next level of capability.

Concerning battery chemistries and fuel cells, in the near term (up to 5 years), incremental power and energy performance improvements will continue to be made in the area of rechargeable lithium ion batteries. Lithium ion batteries will see broader military and commercial application, and significant cost reductions will be made as the manufacturing base matures. Near-term availability of small, JP-8 fuel-compatible engines is expected. There is mid-term (5 to 15 years) potential for significant incremental performance advances through the discovery and development of alternative lithium ion chemistries. Mid-term development of fuel cells with moderate power levels (100 W class) will begin to be introduced based on low-weight hydrocarbon fuels (e.g., propane). The technical feasibility of heavy hydrocarbon-fueled (e.g., JP-8) fuel cell systems will be proven at the kilowatt class. In the long term (beyond 15 years), there is the potential for revolutionary improvements through the discovery and development of completely new battery chemistries and designs. Figure 21 charts a course for power and propulsions capabilities and technologies.

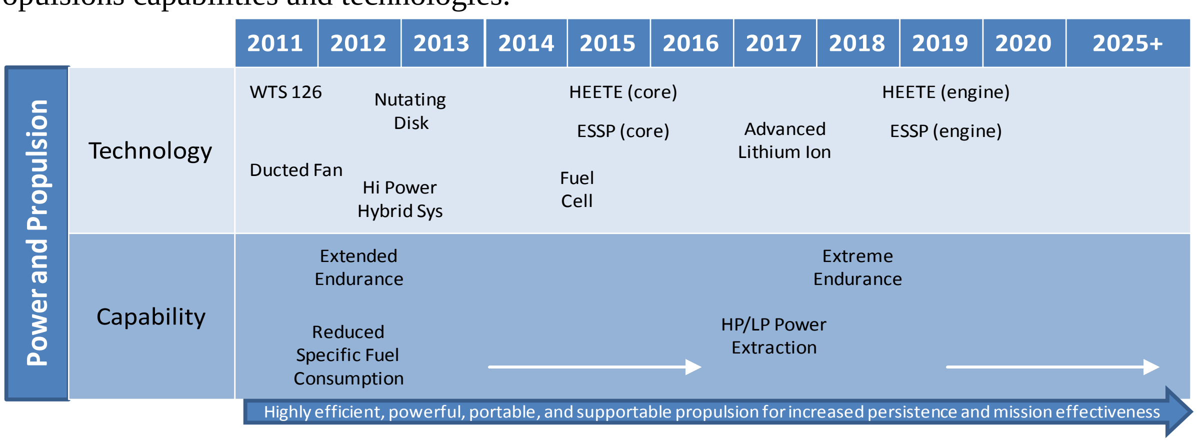

Figure 21. Propulsion and Power Roadmap.

10 MANNED-UNMANNED (MUM) TEAMING

10.1 Functional Description

For this discussion, MUM teaming refers to the relationships established between manned and unmanned systems personnel prosecuting a common mission as an integrated team. More specifically, MUM teaming is the overarching term used to describe platform interoperability and shared asset control to achieve a common operational mission objective. This term also includes concepts of "loyal wingman" for air combat missions and segments of missions such as MUM air refueling. This capability is especially vital for missions such as target cueing and handoff between manned and unmanned systems, where the operators not only require direct voice communications between the participants, but also a high degree of geospatial fidelity to accurately depict each team member's location with regard to the object being monitored.

MUM teaming was first employed in the late 1960s when the USAF flew AQM-34 equipped with Maverick missiles from airborne C-130 aircraft. Over the intervening years, other experimental UAS were flown from manned aircraft and during the Predator ACTD from a submarine. In 2002, the USAF demonstrated the ability to fly the MQ-1 from a flying C-130 also equipped with a FMV camera to prove a rapid, small-footprint deployment capability, and the ability to cooperatively prosecute targets with onboard and off-board systems. The Army also conducted MUM demonstrations beginning with the Airborne Manned/Unmanned Systems Technology (AMUST) Demonstration in 2001 with a follow-on Hunter Standoff Killer Team (HSKT) ACTD in 2006. During that demonstration, an AH-64D executed level of interoperability (LOI) 4 control of a RQ-5B Hunter UAS during a live fire exercise where Apaches lased for their own Hellfire missiles with the Hunter payload.[60] At these demonstrations, the Army Aviation Applied Technology Directorate successfully integrated a Mobile Commander's Associate[61], including UAS control, Link 16, and other various data links, into an Army airborne C2 system. This integration enabled an airborne C2 system operator located in a UH-60 Black Hawk helicopter to control a Hunter UAS and its sensor, for the first time, as well as send and receive tactical information in flight between strike aircraft such as the FA-18, and reconnaissance aircraft such as JSTARS.[62] To date, each of the demonstrations merely changed the location of the control of the vehicle off the ground. This

[60] "Hunter Standoff Killer Team Successfully Tests Military Interoperability," 16 September 2005, http://aero-defense.ihs.com/news/2005/navy-air-systems-link-16.htm?WBCMODE=presenta.
[61] "Mobile Commander's Associate (MCA), Lockheed Martin, USA", http://defense-update.com/products/m/mca.htm .
[62] Colucci, Frank, "MUM's The Word," *Rotor & Wing Magazine*, 1 November 2004, http://www.aviationtoday.com/rw/military/attack/1817.html.

change was still significant because of the ability to more effectively conduct certain types of missions through collaboration of all assets.

10.2 Today's State

Practical applications of MUM teaming continue to evolve as confidence in unmanned vehicle reliability and functionality matures. Employment concepts are limited by data links, vehicle control interfaces, and level of autonomy. One recent example of practical application is when the USMC fielded a laser designation capability for Shadow as an enhancement/enabler of sensor-to-shooter operations for enemy/target of interest engagement in April 2010.

10.2.1 Unmanned Ground Vehicles (UGVs)

MUM teaming has steadily increased as technology has improved and users have found new and innovative methods to exploit this enhanced mission capability. Current missions include reconnaissance, surveillance, and target acquisition (RSTA); transport; countermining; explosive ordnance disposal; and the use of armed unmanned tactical wheeled vehicles for checkpoint security inspections. The integration of one-system remote video terminal (OSRVT) technology and distributed UGV control into ground combat vehicles is leading to the adaptation of TTPs because all parties now receive the same picture at the same time, regardless of their location.[63] With over 4,000 OSRVT or like systems fielded between the Army, USMC, and USAF to date, it is clear that MUM teaming is becoming ever more pervasive in ground operations. These developments have also been the catalyst for the creation of the common robotic controller, a joint project between the Army and USMC to develop a universal, wearable controller to operate a wide variety of unmanned systems, including UGVs, UA, and unattended ground sensors. This effort is currently aimed at smaller platforms, but could be transitioned to include limited control (i.e., payload only) for larger platforms as the technology matures.

[6363] Lt. Col. Adam Hinsdale, former Chief, UAS Division, Department of the Army Aviation Directorate, was quoted in October 2007: "Everyone, regardless of the platform, receives the same information at the same time, leading to true interoperability, the Army's key goal. The OSRVT is a vital component of manned/unmanned teaming, allowing all elements, air and ground, to view the same synchronized area of interest simultaneously for coordinated engagement, with either kinetic or nonkinetic effects." *UAS Video Terminal Connects Boots On The Ground To Eyes In The Sky*, by Kim Henry, Redstone Arsenal, AL, (AFNS), 9 October 2007.

10.2.2 Unmanned Aircraft Systems (UAS)

MUM teaming has been successfully demonstrated in combat operations to provide CCDRs with enduring surveillance of hostile activities in real/near-real time to accurately geolocate potential targets, to laser-designate targets, and to provide battle damage assessment. UAS have proven successful in performing their missions largely because they are able to remain visually and aurally undetected by hostile forces. They are providing the CCDR with critical tactical data, which are used to plan and support combat operations. When used in support of ground operations, UAS have proven invaluable in providing near-real-time intelligence to commanders engaged in combat and have directly contributed to successful mission completion. Armed UAS have the ability to engage targets directly or cooperatively with other air and ground systems. Additionally, LOI 3 (control and monitoring of the UA payload in addition to direct receipt of UA data) has been demonstrated successfully in combat operations with attack helicopter crews. The attack helicopter crew is able to see on their cockpit display the sensor outputs that give them overhead views to the target and surrounding area. This capability greatly enhances the attack helicopter crew's ability to identify, classify, and verify target locations to reduce the risk of fratricide. In September of 2010, the Army conducted an integration exercise featuring Apache helicopter pilots controlling Shadow, Hunter and Raven UAs.

The success of the exercise resulted in the inclusion of the LOI 2 and 3 UA control requirement into the AH-64, which gives the manned aircraft sensor and flight-path control and monitoring of the UA (less launch and recovery). The Apache Block III initial fielding is scheduled for 2012 and will incorporate LOI 2, 3, and 4 UA control. The AH-64 BLK III will have the capability to receive real-time UA FMV and the associated metadata (LOI 2), control the UA electro-optical/infrared (EO/IR) payload (LOI 3), and dynamically task the UA flight path (LOI 4), all from the front seat of the Apache. The initial combat operations in Afghanistan and Iraq validated the urgent need to integrate UAS capabilities with manned aircraft, specifically the attack platforms. Commanders recognized that they could dramatically reduce sensor-to-shooter times and improve situational awareness of helicopter pilots, while drastically reducing collateral damage and the potential for fratricide. They crafted an Operational Needs Statement for attack helicopter MUM teaming capability that led to a rapid prototype system for the Apache called Video from Unmanned Aircraft Systems for Interoperability Teaming – Level 2 (VUIT-2). The VUIT-2 system allows the AH-64 crew to receive video feeds from UA utilizing C-Band transmission. The Army has renamed this effort MUMT-2 and expanded it to UH-60 Black Hawk and OH-58D Kiowa Warriors.

Current MUM teaming applications are limited due to the fact the control interface currently requires a dedicated crew member to fly the UAS while another crew member flies the manned aircraft. However, some automated MUM mission segments are being developed. For example, the Navy and USAF have developed and demonstrated technology for MUM air refueling and have simulated cooperative MUM air combat missions.

10.2.3 Unmanned Maritime Systems (UMS)

MUM teaming is critical for the maritime environment. This is especially true for the undersea domain where physics prevent man from safely performing tasks to the same fidelity. There are many different aspects of MUM teaming for UMS that have been explored and implemented in various degrees: long-endurance undersea gliders send data ashore and receive human-initiated mission updates in near real-time; UUVs enable efficient port security, harbor defense, and mine clearance operations through change detection and autonomous investigation of mine-like objects; likewise, UUVs extend the footprint of manned hydrographic and bathymetric survey platforms to gather higher volumes of data while enabling people to focus on the tasks that require human oversight. Near-term enhancement, development and codification of Water Space Management/Prevention of Mutual Interference (WSM/PMI) doctrine and procedures will allow sophisticated collaboration between submarine or surface vessel operations and unmanned assets for mission accomplishment. Given the inherent challenges of the maritime environment, the future of MUM teaming will consist of multiple types of unmanned systems (UUV, USV, UAV, UGV) used collaboratively with manned platforms to collect, process, exploit, and disseminate data. An enduring and integrated net of undersea sensors partnered with USVs or UAVs for communication and controlled from a common command center will revolutionize how undersea missions are conducted by bringing transparency to an otherwise opaque battlespace. All maritime missions will benefit from reduced timelines and improved accuracy of information from which the combat commander can make engagement decisions.

10.3 Problem Statement

While strides have been made over the past decade to further enhance MUM teaming capabilities, several challenges persist that will continue to affect the amount of time it takes this technology to transition from the invention and adaptation phase to the acceptance phase. This timing will also directly affect the development of MUM teaming TTPs, which in turn will dictate the speed of MUM teaming from CONOPS into DoD doctrine.

Some of these challenges are technical. They range from near-term issues such as the limited ability to integrate and deconflict various radio frequencies across a secure communications network, to far-term issues such as the ability of one person to control multiple UASs and UGVs simultaneously while flying his or her primary aircraft. This ability requires a high degree of hardware and software interoperability, scalable autonomy, human system interfaces (HSIs), new collaborative control algorithms, and network mission tools. The platforms must do significant levels of onboard processing to not only reduce bandwidth required, but also collaborate with other unmanned vehicles without operator input. Other technical challenges result from the need to make tradeoffs between size, weight, and power limitations on the various platforms and the desire for increased performance and capability. One of the biggest potential challenges to MUM operations stems from the Services' desire to introduce swarms (large numbers

of micro-UAS operating semi-autonomously) into military operations with other manned and unmanned systems.

> "Everyone, regardless of the platform, receives the same information at the same time, leading to true interoperability; this is the Army's key goal.
>
> - *Lt. Col. Adam Hinsdale,*
> *Chief, UAS Division,*
> *Department of the Army Aviation Directorate*

Other MUM missions have different challenges including cargo, air refueling, interdiction in contested areas, electronic/network attack (EA), suppression of enemy air defenses (SEAD), and other traditional air combat missions. The ability to communicate from a highly maneuverable aircraft to a highly maneuverable future UAS will require significant advances in autonomy and HSI. This advancement can be compounded if LPI communication is needed for missions such as EA, SEAD, or control of long-dwell insect-size vehicles collecting information inside buildings.

10.4 Way Ahead (2011–2036)

Some key events will affect the future of MUM teaming over the next 25 years. As improvements in communications and sensor technologies evolve, new tactics will surely follow. For instance, it should be expected that there will be a shift away from the current reliance on video with operators incorporating other sensors (such as audio or tactile) to augment the tactical picture. Also, as commanders continue to integrate multiple manned and unmanned systems into their operations, they will soon be able to implement a "field of view" approach, similar to the "God's eye" perspective seen in many current video games. A commander will be able to view a target from multiple perspectives (i.e., UGV, UAS, or manned sensors), using multiple sensors, to obtain more robust and comprehensive situational awareness. As MUM advances, new HSI and autonomy will change the role of people in mission execution and dramatically increase their effectiveness.

The most significant advances in MUM operations will begin as Services migrate away from the current closed-loop scenario between sensor and shooter to networked systems. High endurance UAS already have mission teams geographically separated from the platform and from each other. Wide-area sensors are also changing the paradigm on STANAG 4586 LOIs and USIP development. Employing MUM segments as nodes on a larger network will change how missions are executed and will dramatically affect the combat effectiveness.

Investments in technologies such as automated air refueling, tactical data link control of maneuverable aircraft, and autonomy in the near term will enable "loyal wingman" operations. The effectiveness of air missions will not be achieved by a collection of assets, but collaboration between manned and unmanned systems within the context of a network. These nodes on the network will have scalable transparent control, not the brittle closed-loop control and inflexible autonomy algorithms used today.

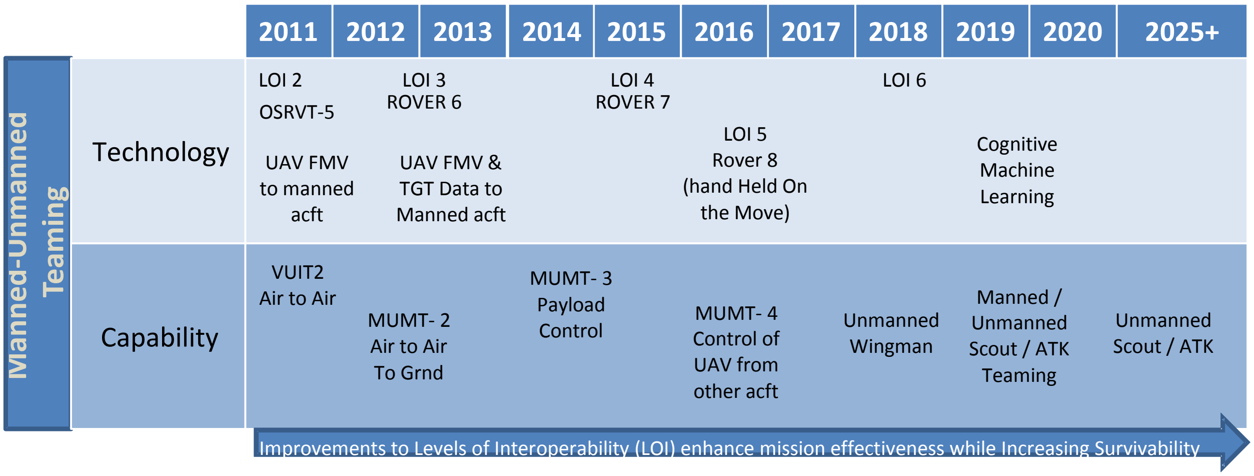

Figure 22. Manned Unmanned Teaming Roadmap.

The rapid growth in the OPTEMPO and demand for unmanned systems is a validation of their value to the CCDR. New concepts for the use of UAS, UGS, and UMS will result from experiences gained in combat. In the near future, it is likely that MUM teaming will be incorporated into an expanded set of operations.

11 SUMMARY

DoD has made great strides in developing, producing, and fielding unmanned systems. These systems have been effectively integrated across air, ground, and maritime domains to support a wide range of Joint warfighting needs. The inherent advantages of unmanned systems, including persistence and reduced risk to human life, have been clearly demonstrated in combat operations in Iraq and Afghanistan.

DoD envisions the continued expansion of unmanned systems in the future force structure. This expansion will include fielding additional systems in capability areas already supported by unmanned technologies, but also expanding into new mission areas not currently covered. As DoD defines a path toward this vision, a common set of challenges is apparent that cuts across all military Services, budgets, and all three domains of air, ground, and maritime. DoD, working together with industry, academia, and other Government agencies, will continue to map an affordable path forward to address these common challenges. Success in addressing the common issues discussed in this document and following the technology roadmaps summarized in Figure 23 (see next page) is critical to achieving the full potential offered by unmanned systems technologies.

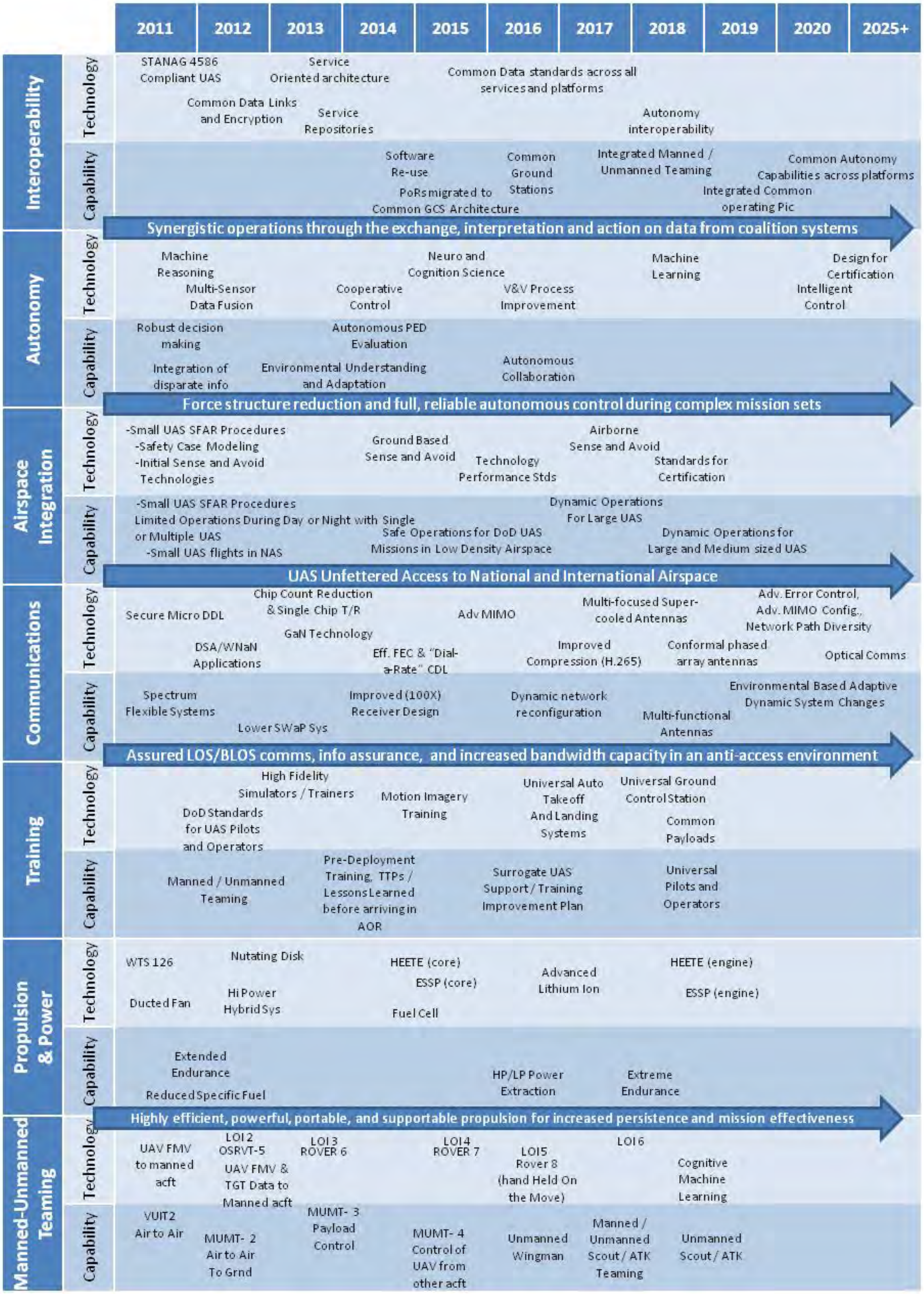

Figure 23. Summary of Technology Roadmaps.

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APPENDIX B: ABBREVIATIONS

4G	fourth generation
AAM	air-to-air missile
AATD	Army Aviation Applied Technology Directorate
ABSAA	airborne sense and avoid
ACAT	Acquisition Category
ACTD	Advanced Concept Technology Demonstration
ADC	analog-to-digital converter
AECV	All Environment Capable Variant
AEODRS	Advanced Explosive Ordnance Robotic System
AI	airspace integration
AMRDEC	Aviation and Missile Research, Development and Engineering Center
AMUST	airborne manned/unmanned systems technology
APU	auxiliary power unit
ASM	air-to-surface missile
ASW	anti-submarine warfare
ATS	air traffic services
AvGas	aviation gasoline
BA	Battlespace Awareness
BAMS	broad-area maritime surveillance
C2	command and control
CA	collision avoidance
CAP	Combat Air Patrol
CBP	Customs and Border Protection
CCDR	Combatant Commander
CDL	common data link
CFR	Code of Federal Regulations
CNO	Chief of Naval Operations
COA	Certificate of Waiver or Authorization
CONEMP	concept of employment
CONOPS	concept(s) of operations
COP	common operational picture
COTS	commercial, off-the-shelf
CSS	combat services support
CV	cargo variant
DDL	digital data link
DHS	Department of Homeland Security
DIMA	DARPA Interference Multiple Access
DLI	data link interface
DoD	Department of Defense
DOTMLPF	doctrine, organization, training, materiel, leadership and education, personnel, and facilities
DOTMLPF-P	doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy
DPRK	Democratic People’s Republic of Korea
DSA	dynamic spectrum access
DSPM	domain service portfolio management
EAU	electrical accumulator unit
EMI	electromagnetic interference
EMS	electromagnetic spectrum
ESSP	efficient small scale propulsion
EW	early warning
FA	Force Application
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FCS	Future combat system
FEC	forward error correction

FMV	full-motion video
GaAs	gallium arsenide
GaN	gallium nitride
GBSAA	ground-based sense and avoid
GCS	ground control station
GCU	generator control unit
GDP	gross domestic product
gMAV	Gasoline-powered Micro Air Vehicle
GPS	global positioning system
GUI	graphical user interface
HAIPE	High Assurance IP Encryption
HEETE	highly efficient turbine engine
HSKT	Hunter Standoff Killer Team
ICAO	International Civil Aviation Organization
IED	improvised explosive device
I-IPT	Interoperability Integrated Product Team
IPSEC	Internet Protocol Security
ISR	intelligence, surveillance, and reconnaissance
ITU	International Telecommunication Union
JAUS	Joint Architecture for Unmanned Systems
JCA	Joint Capability Area
JCGUAV	Joint Capability Group Unmanned Aerial Vehicle
JMOC	Joint Maritime Operations Center
JSIDL	JAUS Service Interface Definition Language
JTRS	Joint Tactical Radio System
JTS	JAUS Tool Set
LCS	littoral combat ship
LOS	line of sight
LRU	line replaceable unit
MALE	medium-altitude, long-endurance
MDF	multisensor data fusion
MIMO	multiple-input, multiple-output
MISM	motion imagery systems matrix
MISP	motion imagery standards profile
MOA	Memorandum of Agreement
MPG	multiple power pod gas generator
MUM	manned-unmanned
NAS	National Airspace System
NII	national information infrastructure
NSA	National Security Agency
NSRDEC	Natick Soldier Research, Development & Engineering Center
NUWC	Naval Undersea Warfare Center
OA	open architecture
ODUSD(R)RTPP	Office of the Deputy Under Secretary of Defense (Readiness), Readiness and Training Policy and Programs
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
OPTEMPO	operational tempo
OSD	Office of the Secretary of Defense
OSRVT	one-system remote video terminal
OUSD(AT&L)	Office of the Under Secretary of Defense, Acquisition, Technology and Logistics
PEO(LMW)	Program Executive Officer of Littoral and Mine Warfare
QRF	quick reaction force
RFI	request for information
ROV	remotely operated vehicle
RS-JPO	Robotic Systems Joint Project Office
RSTA	reconnaissance, surveillance, and target acquisition
S&T	science and technology

SAA	sense and avoid
SAE	formerly known as the Society of Automotive Engineers, now known simply as SAE
SAR	synthetic aperture radar
SATCOM	satellite communications
SBIR	small business innovation research
SBU	sensitive but unclassified
SDO	standards development organization
SDS	spectrum-dependent system(s)
SF	special forces
SFC	specific fuel consumption
SIGNT	signals intelligence
SOA	service oriented architecture
SOCOM	Special Operations Command
SOFC	solid oxide fuel cell
SSPA	solid state power amplifier
SSPC	solid-state power controller
SSRA	spectrum supportability and risk assessment
STANAG	Standardization Agreement
STD-CDL	standard common data link
STUAS	small tactical unmanned aircraft system(s)
SuDDL	secure micro-digital datalink
SWaP-C	size, weight, power, and cooling
SWCC	special warfare combatant-craft crewman
TOC	total ownership costs
TPED	tasking, processing, exploitation, and distribution
TTP	tactics, techniques, and procedures
UA	unmanned aircraft
UAS	unmanned aircraft system(s)
UCAS	unmanned combat aircraft system
UGS	unmanned ground system(s)
UGV	unmanned ground vehicle
UMS	unmanned maritime system(s)
UMV	unmanned maritime vehicle
USC	United States Code
USIP	UAS System Interoperability Profiles
USV	unmanned surface vehicle
UUV	unmanned underwater vehicle
UW	unconventional warfare
VAATE	versatile affordable advanced turbine engine
VBSS	visit, board, search, and seizure
V&V	verification and validation
WSARA	Weapon Systems Acquisition Reform Act
WGS	Wideband Global SATCOM
WNaN	Wireless Network after Next
WRC	Worldwide Radio Communication Conference

APPENDIX C: GLOSSARY

Analysis and Production – The ability to integrate, evaluate, and interpret information from available sources and develop intelligence products that enable situational awareness.

Battlespace Awareness – The ability to understand dispositions and intentions as well as the characteristics and conditions of the operational environment that bear on national and military decision-making.

Building Partnerships – The ability to set the conditions for interaction with partner, competitor or adversary leaders, military forces, or relevant populations by developing and presenting information and conducting activities to affect their perceptions, will, behavior, and capabilities.

Collection – The ability to obtain required information to satisfy intelligence needs.

Command and Control – The ability to exercise authority and direction by a properly designated commander or decision maker over assigned and attached forces and resources in the accomplishment of the mission.

Communicate – The ability to develop and present information to domestic audiences to improve understanding; and, to develop and present information to foreign audiences to affect their perceptions, will, behavior and capabilities to further U.S. national security or shared global security interests.

Communicate Intent and Guidance – The ability to promulgate a concise expression of the operational purpose, assessment of acceptable operational risk, and guidance to achieve the desired end state.

Decide – The ability to select a course of action informed and influenced by the understanding of the environment or a given situation.

Deployment and Distribution – The ability to plan, coordinate, synchronize, and execute force movement and sustainment tasks in support of military operations. Deployment and distribution includes the ability to strategically and operationally move forces and sustainment to the point of need and operate the Joint Deployment and Distribution Enterprise. (JL(D) JIC pg 5 and pages 14-21)

Direct – The ability to employ resources to achieve an objective.

Engagement – The ability to use kinetic and non-kinetic means in all environments to generate the desired lethal and/or non-lethal effects from all domains and the information environment.

Force Application – The ability to integrate the use of maneuver and engagement in all environments to create the effects necessary to achieve mission objectives.

Health Readiness – The ability to enhance DoD and our Nation's security by providing health support for the full range of military operations and sustaining the health of all those entrusted to our care.

Information Transport – The ability to transport information and services via assured end-to-end connectivity across the NC environment.

Intelligence, Surveillance and Reconnaissance – The ability to conduct activities to meet the intelligence needs of national and military decision-makers.

Intelligence, Surveillance and Reconnaissance Dissemination – The ability to present information and intelligence products that enable understanding of the operational environment to military and national decision-makers.

Intelligence, Surveillance and Reconnaissance Planning and Direction – The ability to synchronize and integrate the activities of collection, processing, exploitation, analysis and dissemination resources to meet information requirements of national and military decision-makers.

Kinetic Means – The ability to create effects that rely on explosives or physical momentum (i.e., of, relating to, or produced by motion).

Logistics – The ability to project and sustain a logistically ready joint force through the deliberate sharing of national and multi-national resources to effectively support operations, extend operational reach and provide the joint force commander the freedom of action necessary to meet mission objectives.

Maneuver – The ability to move to a position of advantage in all environments in order to generate or enable the generation of effects in all domains and the information environment.

Maneuver to Engage (MTE) **–** The ability to move to a position of advantage in all environments in order to employ force.

Maneuver to Influence (MTInfl) **–** The ability to move to a position of advantage in all environments in order to affect the behavior, capabilities, will, or perceptions of partner, competitor, or adversary leaders, military forces, and relevant populations.

Maneuver to Insert (MTI) **–** The ability to place forces at a position of advantage in all environments.

Maneuver to Secure (MTS) **–** The ability to control or deny (destroy, remove, contaminate, or block with obstacles) significant areas, with or without force, in the operational area whose possession or control provides either side an operational advantage.

Mitigate – The ability to minimize the effects and manage the consequence of attacks (and designated emergencies on personnel and physical assets.

Monitor – The ability to adequately observe and assess events/effects of a decision.

Net-Centric – The ability to provide a framework for full human and technical connectivity and interoperability that allows all DoD users and mission partners to share the information they need, when they need it, in a form they can understand and act on with confidence, and protects information from those who should not have it.

Non-Kinetic Means – The ability to create effects that do not rely on explosives or physical momentum. (e.g., directed energy, computer viruses/hacking, chemical, and biological).

Prevent – The ability to neutralize an imminent attack or defeat attacks on personnel (combatant/non-combatant) and physical assets.

Processing / Exploitation – The ability to transform collected information into forms suitable for further analysis or action.

Protection – The ability to prevent/mitigate adverse effects of attacks on personnel (combatant/non-combatant) and physical assets of the United States, allies and friends.

Shape – The ability to conduct activities to affect the perceptions, will, behavior, and capabilities of partner, competitor, or adversary leaders, military forces, and relevant populations to further U.S. national security or shared global security interests.

Supply – The ability to identify and select supply sources, schedule deliveries, receive, verify, and transfer product and authorize supplier payments. It includes the ability to see and manage inventory levels, capital assets, business rules, supplier networks and agreements (to include import requirements) as well as assessment of supplier performance.

Understand – The ability to individually and collectively comprehend the implications of the character, nature, or subtleties of information about the environment and situation to aid decision-making.

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US ARMY
DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA